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AN ELEMENTARY MANUAL

ON

INDIAN WOOD TECHNOLOGY

BY

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acropetally . . .	Developing from below toward the apex.
albuminoid . .	Any of a number of substances resembling the proteids in many respects. See proteids.
amino-acid . . .	An acid in which a portion of the non-acid hydrogen has been replaced by the amino (NH_2) group.
amorphous . . .	Having no determinate form; shapeless.
anastomose . . .	To join or unite like the parts of a network.
annulus . . .	A ring; a ringlike part, structure, space, or marking.
anomalous . . .	Deviating from a general rule; abnormal: irregular.
apical . . .	At, near, or belonging to an apex.
arborescent . .	Resembling a tree; tree-like.
aromatic . . .	Of, pertaining to, or containing aroma. fragrant; strong scented.
articulate . . .	Jointed; provided with joints.
asexual . . .	Having no sex; said of spores, etc., which are not the result of a sexual act
autonomous . . .	Independent; self-sufficient; see heteronomous.
biseriate . . .	Arranged in two series or rows.
carbohydrate . .	A compound composed of carbon, hydrogen, and oxygen. Examples—sugars, starches and cellulose.
Carboniferous .	Of, pertaining to, or designating a Paleozoic period following the Devonian when the coal measures were formed; a geologic term.
carnivorous . . .	Flesh-eating.
cellulosic . . .	Of the nature of, or consisting of, cellulose.
chlorophyl . . .	The green coloring matter of plants; of importance in photosynthesis.
chromatin . . .	A protoplasmic substance (proteid) in the nuclei of cells which stains deeply with basic dyes.
cladoposis . . .	Twig or branch casting.
cortex	Bark; the tissues outside the cambium of a tree, taken collectively.
coterminous . .	Adjacent, neighbouring, bordering, contiguous.

Glossary of terms used in the text—*contd.*

Cretaceous . . .	Of, pertaining to, or designating the last Mesozoic period; a geologic term.
cutin	A waxy substance which is infiltrated with cellulose to form the cuticle of a plant.
dendroid .	Tree-like; resembling a tree. See arborescent.
de novo . . .	Arising anew.
dermatogen . . .	The thin external meristematic tissue of growing points to which the epidermis is traceable.
edaphic . . .	Pertaining to, or influenced by, soil conditions rather than climatic factors and hence local.
ephemeral . . .	Short-lived; beginning and ending in a day.
epiphyte . . .	A plant growing upon another plant but obtaining no sustenance from it.
echelon . . .	An arrangement of a body of troops with the divisions drawn up in parallel lines but each somewhat to the right or left of the one in the rear, like a series of steps.
excurrent . . .	Having the axis prolonged forming an undivided main stem. Example—the trunks of coniferous trees.
fusiform . . .	Spindle-shaped; tapering at each end.
gamete . . .	A sexual cell or nucleus bearing the inheritable characteristics of an organism.
herbivorous . . .	Eating or living on plants.
heteronomous . .	Subject to the law of another; not independent; see autonomous.
hygroscopic . . .	Readily absorbing and retaining moisture.
insolation . . .	Exposure to the rays of the sun.
intercalary . . .	Inserted between or in the midst of; interpolated.
liana	A climbing woody plant.
lignin	A mixture of substances which with cellulose makes up the essential part of cell walls in woody tissue.
maturation . . .	Process of coming to full maturity or development.
meristem . . .	Embryonic or undifferentiated tissue the cells of which are capable of repeated division.

Glossary of terms used in the text—*contd.*

-merous	A suffix meaning divided into (so many) parts.
mesophyll	The green parenchymatous tissue between the epidermal layers of a leaf.
metabolism	The sum of the processes concerned with the building up or breaking down of protoplasm.
microscopy	Investigation or examination with the microscope.
multiseriate	Arranged in several series or rows.
muriform	Resembling courses of bricks in arrangement.
necrosis	Death; mortification.
occlude	To close; to shut by closing a passage.
orbicular	Like an orb; circular; spherical.
orifice	A mouth or aperture; opening; hole.
osmosis	A kind of diffusion which takes place between two miscible liquids separated by a permeable membrane; diffusion is most rapid from the less dense to the more dense liquid.
osmotic pressure	Pressure resulting from osmosis.
parasite	A plant or animal living upon another organism from which it obtains its food, at least in part.
parietal	Of or pertaining to the wall.
pectin	A neutral "jelly like" substance occurring in many plant tissues as a part of the walls or sap.
perforation	A hole or holes resulting from perforating or piercing a substance or body.
periblem	The zone of tissue lying between the dermatogen and plerome in the growing point of a shoot to which the primary cortex is traceable.
pericarp	The ripened and variously modified walls of the ovary.
periclinal	Parallel with the circumference.
peripheral	Adjective term for periphery. See periphery.
periphery	The line or surface bounding a rounded body.
permutation	Any one of all the possible arrangements of a number of objects in a series.
photosynthesis	The process of constructive metabolism in the chlorophyll-containing tissues of plants exposed to light.

Glossary of terms used in the text—*contd.*

phyllum	One of the primary divisions of the animal or vegetable kingdom, so-called because the members are supposed to have a common descent.
phylogenetic . .	Adjective term for phylogeny. See phylogeny.
phylogeny . . .	The race history of an animal or vegetable type.
pit	A thin place in a cell wall, not a perforation.
plerome . . .	The central portion of the primary meristem at the growing points of stems and roots. The stele is derived from the plerome as the tissues differentiate.
proteids . . .	Complex organic compounds present in all living cells and consisting of carbon, oxygen, nitrogen, and hydrogen, and usually traces of sulphur.
punctate . . .	Dotted with minute spots or depressions.
pungent . . .	Causing a sharp sensation as of taste or smell; acrid.
resiniferous . . .	Resin bearing or secreting.
resumé . . .	A summary; an abridgment.
reticulum . . .	A net-like structure; a network.
saprophyte . . .	An organism devoid of chlorophyll living on dead or dying organic material.
scalariform . . .	Resembling a ladder; having a ladder-like formation.
sclerosed . . .	Hardened; indurated; affected with sclerosis.
senile	Of, pertaining to, or characteristic of, old age.
septum . . .	Any dividing wall, partition, or the like, especially in an organism.
sexual . . .	Pertaining to sex or the sexes; relating to either the male or the female sex.
spireme . . .	The chromatin of a cell nucleus when in the form of a filament.
sporadic . . .	Occurring singly or in scattered instances; separate; single.
sporophyte . . .	In plants exhibiting alternation of generations, the generation which bears asexual spores.
sporophytic . . .	Adjective term for sporophyte. See sporophyte.

Glossary of terms used in the text—*concld.*

stele	The central cylinder in the stems and roots of vascular plants which differentiates out from the plerome. See plerome.
suberin	A fatty or waxy infiltration product characteristic of corky tissues.
taxonomy	Classification, especially the classification of plants and animals according to natural relationships.
thallophyte	Any one of the plants belonging to the phyllum Thallophyta.
thallus	A simple vegetative plant body which is usually not differentiated into leaves, stems, and roots; characteristic of Thallophytes.
translucent	Transmitting light imperfectly; imperfectly transparent.
traumatic	Of, pertaining to, or due to, a wound or injury.
Triassic	Of the age of, or pertaining to, the Trias, the geologic period between the Permian and the Jurassic.
turgor	A state of normal tension or rigidity in living plant cells caused by the pressure of the water contents against the elastic cell membranes.
uniseriate	Arranged in one series or row.
vernal	Of or pertaining to the spring.

PREFACE.

While Officer in Charge of the Section of Wood Technology at the Forest Research Institute, Dehra Dun, the imperative need for a Text Book dealing with the anatomy and identification of Indian timbers first came to my attention. As a Sectional Officer I had occasion annually to give a series of elementary lectures covering wood anatomy to the Provincial students of the Forest College and the dearth of information bearing on Indian timbers at once became apparent. I was compelled to rely on texts which, while they depicted and explained the structure of extra-tropical woods in detail, left one wholly in the dark in so far as Indian timbers were concerned—a state of affairs which not only tended to nullify student interest in this important branch of wood utilization but at the same time to detract from efficient pedagogy. The apathy of students in a study of trees and timbers which the majority of them will never see, is quite understandable and I have ventured to offer a remedy, namely, an elementary treatise of wood anatomy, couched in terms of Indian timbers and supplemented by keys for pocket lens identification of a restricted number of species. As time goes on and our knowledge of the diagnostic features of Indian woods becomes further amplified, the scope of such keys should be enlarged until all of the commercial woods are included but in such case the desirability of parceling out the information to provinces or at least the natural timber divisions of India is obvious. The present treatise is to be considered as but a start in the right direction and the author hopes that it may contribute in its small way to a better understanding of wood, more especially Indian woods, and to their wider utilization.

In my approach to the subject I may be accused by the foresters of India as being unduly didactic,—as devoting too many pages to the principles of botany and plant histology with a resulting sacrifice in the utility of the work. For such critics I would answer that this pamphlet is intended primarily for students undergoing preparatory training in the forest schools of India, not for men who have been inducted into the forest service and to whom a

wider range of knowledge and experience might make these pages seem unduly elementary. I have found as a teacher that in the introduction of the subject of wood anatomy time devoted to the elementals and to the building of a broad foundation is not time wasted by any means. To obtain a grasp of a subject, a student must be made to understand the fundamentals upon which it is based, the foundation upon which it rests. Once these ideas are inculcated, the approach to the heart of the study is rendered comparatively easy and an interest is engendered which promises well for the assimilation of the subject proper. With this idea in mind I have ventured to go so far as to point out that the unit of structure of organisms, be they plant or animal, is the cell, wherein plant and animal cells differ in their general features, that cells form aggregates which we term tissues and finally, that wood as we know it commercially is a specialized kind of tissue designed by nature to meet certain needs in the life economy of the plant which we know as a tree and as the ultimate source of timber. Then follows a discussion of the gross and microscopic features of wood in general and a small key for the identification of Indian species. Whether this approach to the subject is happily chosen, only trial with students can determine. I trust my efforts to discuss wood structure in terms of Indian timbers may not have been in vain and that such a start, humble as it may be, may in time lead to a detailed compilation of those anatomical features of which there is such an appalling dearth at the present time. The proper utilization of Indian woods is contingent on a correct interpretation of their technical properties and many of the last in turn are traceable directly to varying anatomical structure. Need I say more to justify the present pamphlet in its bearing on wood utilization?

Acknowledgments are due to Mr. R. S. Pearson, Forest Economist, and to Mr. R. N. Parker, Forest Botanist, for many helpful suggestions bearing on Indian timbers and Indian conditions which have been incorporated in the text. I am also indebted to them for the compilation of a list of the timber trees of India which number some four hundred and their assignment in order of importance into three groups. The key for identification at the end of the text covers but the timbers of the first group,

sixty in all, but this will be amplified in time to include groups two and three, which comprise one hundred and one hundred and forty species respectively.

I desire also to express my appreciation of the work of Babu Ganga Singh, artist in the office of the Forest Botanist, who made the illustrations of the text under my direction; his loyalty and zeal have left nothing to be desired and have contributed materially to the completion of the work.

Finally I wish to express my thanks to the various forest officers stationed at Dehra Dun or who came as visitors to the Forest Research Institute, for their interest and constructive criticism, and likewise to the many foresters in the field who have supplied authentic wood samples. I trust that this Manual may appeal to them as a working nucleus which may lead eventually to a more comprehensive text.

An Elementary Manual on Indian Wood Technology

By

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Forest Research Institute, Dehra Dun.

PART I.

Plants *versus* Animals.

Since wood is of plant origin and results from accumulative growth in trees, a proper understanding and interpretation of it and of its role in nature requires certain fundamental knowledge as regards plants in general, their anatomical structure and physiology, and their relation to that other set of organisms which we know as animals. The pages which follow are in the nature of a foundation and I trust may serve to orientate the student and afford such a view point as will enable him to grasp the many details of the technical discussion which follows.

In contrast to the inanimate things about us, living things are said to be of organic origin; in other words they are endowed with life and pass from juvenile to adult stages and finally to death, for death is the lot eventually of all living things. Each sort has its life problems to solve, problems of nutrition, multiplication, the continuance of a vigorous race, and each has met these in its own way. Infringement of Nature's laws means death, speedy or otherwise and only those organisms survive which are sufficiently plastic in their requirements to adjust themselves to a varying, yes, even a hostile environment. Nature is constantly sorting her life forms, eliminating the unfit, creating anew to meet new demands, continuing those which satisfy her

present need. The "animate" is in a state of flux, its currents often unseen and unappreciated. The trend of evolution for the future is problematical though we may trace the history of its past in our rocks.

But living things fall naturally into two groups, plants and animals, which at first thought seem widely separated, so widely in fact that we may never mistake the one for the other. The animal possesses mobility, the power to move at will from one location to another. It has highly developed circulatory and nervous systems and its tissues, except for the bones and cartilage, are soft and plastic. The plant on the other hand is compelled to spend its whole life in one place. It lacks a nervous system worthy of the name and while it possesses a circulatory system, this is less specialised and utilised wholly in the transportation of water and plant foods. Plant tissues are firmer than those of an animal and differ in their chemical composition.

If we would carry the comparison a bit further we find physiological differences which are even more striking. The plant with its green leaves is autonomous; it possesses the power of manufacturing food from the elements through the energy absorbed from sunlight in the presence of chlorophyl. Where the latter is wanting the organism has assumed a parasitic or saprophytic existence and lives on organic food previously elaborated. The higher animal in contrast is strictly heteronomous, that is, it lacks the ability to manufacture food from the elements but is either herbivorous, when it subsists on compounds previously elaborated by plants, or carnivorous, preying on other animals which in turn are herbivores or carnivores. The ultimate source of all the organic compounds found in nature is in the green parts of plants.*

While the gulf which separates the higher plants and animals is obvious, it is lacking in the simpler forms. Science teaches us that the higher organisms have been evolved from lower and less complex types, the least specialised of which are unicellular. Some of these microscopic plants are mobile, at least for a part of

* Certain exceptions occur in the case of the non-chlorophyllous bacteria where forms are known which build up compounds by chemico-synthesis.

their life cycle. In others, such as the bacteria and fungi, chlorophyl is wanting. The simplest animals have but a rudimentary nervous system and some possess chlorophyl granules whose origin is still a matter of dispute and on occasion, may become attached to a substratum either as individuals or in colonies, thus losing their power of locomotion. Differences which separate the higher plants from the higher animals will no longer suffice. The simple forms of plants and animals intergrade.

PART II.

Classification of Plants.

Division of the Plant Kingdom.

It is convenient to consider the two types of organisms, that is, plants and animals, as belonging to separate kingdoms though, for reasons explained in the preceding pages, the boundary between them must not be considered as too sharply delimited. We may now concern ourselves profitably with a consideration of the divisions of the plant or vegetable kingdom.

The plant kingdom is divided into four sub-kingdoms as follows :—

Thallophytes	algæ, fungi, bacteria, etc.
Bryophytes	liverworts and mosses.
Pteridophytes . . .	ferns, scouring-rushes, horse-tails, club-mosses, and quill-worts.
Spermatophytes . . .	all seed plants including coniferous and deciduous trees.

Some conception of the morphological limits of these groups is essential if one is to acquire a clear understanding of the relation which trees bear to other plants. A brief summing up of their pertinent features follows.

Thallophytes constitute the lowest division of the vegetable kingdom and include the simplest forms of plants. The plant body or thallus exhibits little variation or specialization in structure (though often a wide range of form) and usually carries on its life activities either in water or on a moist substratum. Included in this group are the algæ (pond-scums, sea-weeds, etc.), and the fungi (mushrooms, bracket fungi, etc.), both of which exhibit a remarkable variation in the form and size of the thallus but extreme simplicity in its structure. Many of the simplest Thallophytes are unicellular and some are free swimming and resemble minute animals. Sexuality has become well developed in many forms while in others it is totally lacking.

Bryophytes are best represented by the mosses although a second group (the liverworts) is also included. The Bryo-

phytes show a distinct advance in specialisation over the Thallophytes. This is evinced through the definite establishment of a sexual stage in which the sexes may be distinguished, and an "alternation of generations" whereby a sexual stage or generation is followed by a semi-dependent asexual stage which in turn again gives rise to sexual forms. While more specialised than Thallophytes, Bryophytes are, relatively speaking, simple plants. The plant body is an elementary structure which possesses chlorophyl and is in some cases thalloid, while in others it develops a primitive stem and leaves. True vascular tissue (vascular bundles) is entirely lacking.

Vascular plants make their appearance for the first time in the Pteridophytes, a group which includes the true ferns and what are recognised as fern allies, the horsetails, scouring-rushes, club-mosses and quill-worts. True roots, stems, and leaves, equipped with special conducting or vascular tissue, have become established as definite structures and function as in the seed plant. As in the Bryophytes there is a sexual stage in which the sexes may be distinguished but the sexual organs have become increasingly specialized. This is followed by an asexual stage in which sexless individuals, through spore formation, again give rise to sexual forms. In the higher Pteridophytes it is the asexual or sporophytic stage that has become dominant while the sexual generation has been relegated to an obscure, independent existence or has become actually parasitic on the asexual generation. Pteridophytes were formerly represented by a vast assemblage of plants many of which were arborescent and flourished during the Carboniferous period, contributing largely in the formation of our coal deposits of to-day. Owing to an altered environment and the development of seed plants which are better adjusted to withstand modern conditions the group is now on the wane and is represented only by some 4,000 species.

The dominant plants of to-day are the seed plants or Spermatophytes. They represent the highest type of specialization, though not necessarily the final type Like the Pteridophytes they bear true roots, stems and leaves, and have an independent asexual or sporophytic stage on which the sexual or gametophytic stage is

wholly dependent. The most striking difference lies in the formation of seeds which are dormant structures representing a pause in the development of the new sporophyte designed by nature to tide the plant over unfavourable periods and to insure a wider dissemination. Sexuality is a necessary part of the life cycle and is insured through the transfer of the male elements to the proximity of the female nuclei by means of pollen grains. Following the union of the sex nuclei a young sporophyte or embryo is formed within the ovule or developing seed which, as the latter matures, passes into a dormant condition. Upon subsequent germination of the seed, the young sporophyte again assumes an active existence.

Gymnosperms versus *Angiosperms*.

The Spermatophytes in turn are divided into two classes, the Gymnosperms and the Angiosperms, which are distinguished by the manner in which the seeds are borne. The word gymnosperm is derived from the Greek γυμνος, meaning naked, and σπερμα, seed, and includes those Spermatophytes in which the seeds are not enclosed in an ovary but are borne naked, subtended by scales (*Pinus*) or fleshy structures (*Podocarpus*). Angiosperm comes from the Greek αγγετον meaning vessel, and σπερμα, seed, and embraces those forms in which the seeds are borne enclosed in an ovary which may (*Calophyllum*) or may not (*Tectona*) dehisce at maturity. The boundary between the two groups is sufficiently clear to serve the purpose of classification although it in no way indicates the disparity in numbers and size.

Gymnosperms are very ancient and form but a small part of the present seed-plant vegetation. Some 450 living forms exist to-day which are to be regarded as the surviving remnant of a vast phyllum, which had its genesis in the Carboniferous Period and flourished during the Triassic. Angiosperms were evolved comparatively recently (lower Cretaceous) in a geological sense and now are represented by a vast assemblage of approximately 125,000 species which comprise the bulk of the seed-plant vegetation of the present time. They have been able to attain and hold the ascendancy over other groups because of adaptive features which

they have developed to meet the environmental conditions now in force. The chief superficial characters which separate the group from the Gymnosperms are the presence of the flower with its showy perianth, stamens, and pistil, and the manner in which the ovules or immature seeds are borne enclosed in an ovary.

Dicotyledons versus *Monocotyledons.*

Two sub-classes of Angiosperms are recognised, the Monocotyledons and the Dicotyledons, which are characterized as follows :—

(*a*) Monocotyledons possess but one seed leaf or cotyledon which is terminal on the axis; dicotyledons possess two seed leaves which are lateral.

(*b*) The vascular bundles of monocotyledons are scattered in the stem; those of the dicotyledons are arranged in a ring, or the stem contains a vascular cylinder enclosing a pith.

(*c*) The leaves of the monocotyledons possess closed venation, that is, the veins do not end blindly in the margin which, as a result, is entire; dicotyledons possess leaves with open venation and the margin is often dissected.

(*d*) The flowers of the monocotyledons are chiefly 3-merous; those of the dicotyledons are predominately 4- or 5-merous.

Formerly monocotyledons were believed to be the more primitive because of the greater simplicity of their floral structure. However, modern science has demonstrated that dicotyledons are of more ancient origin and that monocotyledons undoubtedly arose from them as an aberrant off-shoot in comparatively recent times.

Characteristics of Woody Plants.

Since trees are woody plants of dendroid habit we may sum up to advantage those features of woody plants which distinguish them from the herbaceous

type. The following criteria will serve this end though it must be understood at the start that they should be used with reservation:—

1. Woody plants are perennial, that is, they live from year to year. Annuals complete their life cycle within a season and are tided over the winter by their seed. Biennials may produce stems or canes the second year which are semi-woody but the two-year life span precludes their inclusion among typical woody plants.
2. Woody plants possess vascular tissue, that is, specialised conducting tissue. Not all vascular plants are woody by any means as all the herbaceous flowering plants are numbered among the vascular plants. This perquisite, however, excludes the Thallophytes and Bryophytes from the category of woody plants.
3. Woody plants possess an ærial axis or stem which persists from year to year. In the case of a tree the stem is called the trunk or bole. Many perennials fail to be classed as woody plants because they die back to the ground each autumn, the roots persisting through the winter and producing a new stem the following spring. Other plants, as many of the ferns, possess perennial creeping stems and are woody plants in a general sense but not in the strict sense as here employed.
4. Woody plants possess vascular tissue which becomes "lignified" or woody as it matures. This process of lignification is brought about by certain chemical and physical processes which take place in the woody part of the vascular tissue whereby its cell walls are rendered harder, stronger, and more durable than before. All woody tissues become lignified the first year, soon after they attain their ultimate growth, and the process should not be confused with the changes which occur in passing from sapwood to heartwood. Lignification is in no sense

confined to the so-called "woody plants," or, in fact, to vascular tissue. Woody plants possess in proportion more tissue that is lignified than herbaceous plants, and hence seem woody to us.

5. Typical woody plants possess secondary thickening, that is, have a means of thickening their stems by subsequent growth in diameter which is not traceable to terminal growing points. This is achieved through the activities of a growing layer or cambium which is situated just outside the last formed layer of wood and beneath the bark, and produces new wood and new bark yearly which are interpolated between the older wood and bark. This results in the formation of the annual rings which are characteristic of the cross sections of the trunks of trees in temperate regions. Tropical trees are often devoid of annual rings because cambial activity extends over practically the whole year and the resulting wood is quite homogeneous.

But there are arborescent ferns and monocotyledons (palms) which are devoid of secondary thickening of the normal type, in that the woody tissue is not gathered together in a cylinder surrounded by a cambium but is scattered through the stem in the form of isolated vascular bundles. In such arborescent forms subsequent seasonal increase in the thickness of the stem, where it occurs, is due to the continued enlargement, over a period of years, of tissues which had their inception in the apical growing point. This explains the fact that many palms support but a given number of leaves in their crown and new leaves develop only in proportion as some of the older leaves cease to function. In other instances, monocotyledonous stems increase in girth through anomalous secondary thickening, that is, not in the typical way. Finally there are many woody monocotyledons, especially lianas, which exhibit little or no secondary thickening, as in the case of the various species of *Smilax*.

Kinds of Woody Plants.

While trees are woody plants, it does not follow that all woody plants are trees by any means. In general there are three sorts, – trees, shrubs, and lianas, between which no hard-and-fast lines can be drawn. A species may be shrubby near the limits of its range and arborescent elsewhere. For example *Nyctanthes Arbor-tristis* and *Lonicera quinquelocularis* are often shrubs in the Dehra dun* but become trees at their optimum range. Certain species of *Ficus*, as *F. bengalensis* and *F. religiosa* may begin life as epiphytic lianas but ultimately become arborescent. Again, many woody plants which are reduced to dwarfed scraggy shrubs at high elevations in the Himalayas, that is, in the alpine zone, attain to the dignity of large shrubs or even trees at lower altitudes where they are not forced to contend with such a rigorous environment. We may define the kinds of woody plants as follows, keeping in mind, however, that all graduations between such sorts occur in nature :—

1. A tree is a woody plant which attains a height of at least twenty feet in a given locality and usually (not always) has but a single self-supporting stem or trunk.

2. A shrub is a woody plant which seldom exceeds twenty feet in height in a given locality and usually (not always) has a number of stems. Many shrubs have prostrate primary stems imbedded in the soil or leaf-mould which send up persistent secondary branches of fruticose habit. These arise from the horizontal stem at varying intervals and appear as separate individuals.

3. A liana is a climbing woody vine. Lianas climb by twining, clambering, ærial roots, tendrils, etc., and are typical features of tropical rain forests. They are represented in the Dehra Dun flora by species of *Tinospora*, *Hedera*, *Vitis*, and *Bauhinia*.

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* The valley between the western Himalayas and the Siwaliks.

Summary.

The preceding pages should be sufficient to explain to the student the ultimate source of wood; it is of plant origin but results only from the growth activities of certain kinds of plants, namely, Spermatophytes. We may reject Thallophytes and Bryophytes at once as potential sources of timber, since in these groups vascular tissue is wholly wanting and wood is always a product of the vascular system. It may be granted that the ferns and fern allies (Pteridophytes) do possess vascular tissue; we may even go further and state that all pteridophytes are woody but we must discard them as timber producers since the vast majority of existing forms are plants of dwarfed habit which simulate herbs, with creeping persistent stems possessing little or no accumulative (secondary) growth. Certain ferns, notably in Australia, become arborescent, attaining heights of twenty feet or more with trunks which enlarge appreciably but here thickening is of the anomalous type or too restricted to result in a typical stem. Such stems would not yield typical wood upon conversion. As pointed out on page 5, Pteridophytes are very ancient and were formerly represented by a vast assemblage of plants many of which were arborescent and flourished during the Carboniferous period. Where thickening was of the normal type in these prehistoric forms, wood undoubtedly resulted which in some respects resembled the spermatophyte wood of today but such pteridophytes have long been extinct. Timber-producing plants of the present time are confined to the Spermatophytes, that is, to Gymnosperms and Angiosperms.

Living Gymnosperms are all woody and are grouped into four orders, namely, the Cycadales, Coniferales, Gingkoales and Gnetales, of which but one is a source of timber. Some of the Cycads become small trees but in such cases anomalous secondary thickening has developed. The Gingkoales contain but the one species, *Ginkgo biloba*, a native originally of China and now propagated ornamentally throughout the temperate regions of the world. While thickening is normal in *Ginkgo* and the tree satisfies the conditions as a potential source of timber, its restricted distribution precludes it as a commercial source of wood.

We may at the same time reject the Gnetales, since this order is restricted to woody plants of shrubby or liana habit. The source of Gymnosperm, or better said, coniferous wood, is the order Coniferales, a group represented by forty genera and approximately 350 species, mainly inhabitants of temperate, alpine, or sub-boreal regions. Coniferous trees are important sources of timber because of (1) their large stature, in the majority of cases, (2) excurrent trunks which afford the greatest amount of timber upon conversion, (3) growth in pure stands in many localities, (4) their being inhabitants of temperate regions where industrial activity attains its greatest impetus, (5) even-grained soft wood, which readily lends itself to working with tools. Coniferous wood is known as "softwood" in the trade and, as will be explained later in the text, differs materially in its anatomical features from that of Angiosperms.

In contrast to Gymnosperms, the Angiosperms may be defined as a heterogeneous group which has been evolved comparatively recently to meet modern conditions. Herein is contained a vast assemblage of plants,—herbs, shrubs, lianas, and trees, intermixed in bewildering confusion and widely spread over the earth wherever conditions permit of the growth of vascular plants. We distinguish dicotyledons and monocotyledons, through morphological differences explained on page 7, but the last may be rejected at once as a potential source of timber because the great majority are herbaceous; where monocotyledons become arborescent as in the case of the palms and yuccas, the thickening is not of the normal type and the trunks cannot be utilised for lumber.

Angiosperm timber or "hardwood" as it is known, is the product of dicotyledonous trees which exhibit great diversity of form and habitat. In contrast to the conifers, dicotyledons attain their best development in point of species, in tropical regions, but many are found in the temperate and sub-arctic zones. Dicotyledonous trees show less of a tendency to develop pure stands than conifers* and, as the trunks are generally deliquescent, more waste occurs in their conversion into lumber.

In conclusion we may say that wood commercially comes from two sources, "soft" or coniferous wood from the

Dipterocarpus species often form pure stands

Coniferales or cone-bearing trees among Gymnosperms, and "hard" or dicotyledonous wood from trees belonging to the various orders of dicotyledons which in many cases include herbaceous forms as well. It is remarkable but fortunate that two groups of plants as widely separated in time of origin and morphology should have retained the same type of secondary (accumulative) growth.

PART III.

The Cell.

The Cell Defined.

The basis of all life, whether plant or animal is the living substance which we term protoplasm, literally, first or fundamental plasm. Protoplasm differs from inanimate substances in possessing vital characteristics, the capacity for change, growth, and reproduction; it is the inherent seat of life and within it and under its guiding influence, the processes of metabolism proceed. These may consist in the elaboration of new compounds from the elements, that is, *de novo* as in the green parts of plants, or in but readjustments of molecules whereby different substances arise through anabolism (a building up) or katabolism (a breaking down). When viewed under the higher powers of the microscope, plant protoplasm is seen as a hyaline substance of granular or alveolar structure and semi-fluid state; in fact streaming movements can often be detected in favourable material. The chief difference which distinguishes the protoplasm of plants and animals is its greater solidity in the latter group. Both contain many complex nitrogenous compounds (proteids, albuminoids, amino-acids, etc.,) which have yielded, in some cases at least, to the analytical chemist but the mystery of life is still unsolved. We know where life is resident but we do not know of what it consists.

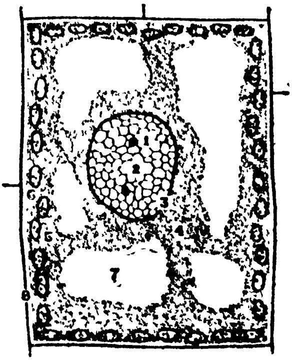

Figure I —Diagrammatic illustration showing the various cell organs. 1. Nucleolus; 2. Nuclear reticulum consisting of linin threads and chromatin granules bathed in nuclear sap; 3. Nucleus surrounded by nuclear membrane; 4. Cytoplasm; 5. Chloroplastids arranged along the cell-wall; 6. Ectoplasmic membrane. In turgid cells, applied closely to the cell-wall; 7. Vacuole filled with cell-sap; 8. Cellulosic cell-wall.

But protoplasm cannot continue to live and to function in nature without some guiding body, some directing agent. This is supplied by the nucleus, one or more as the case may be. A nucleus (Figure I, 3) may be considered as a bit of dense protoplasm of somewhat different chemical composition and structure from the surrounding plasm (cytoplasm) (4) and sharply delimited from it by a thin nuclear membrane. Nuclei vary widely in shape under different conditions and in different plant parts but in naked protoplasm, approach the spherical. The simplest type of cell consists of a nucleus or guiding body with its accompanying cytoplasm, the last in turn protected by a thin membrane of ectoplasm (6), and additionally by a cell wall (8) in the great majority of cases. All organisms whether plants or animals are composed of cells and hence we may define the cell as the "unit of structure" which in the mass makes up the body of the whole. Since wood is such an aggregation of untold millions of dead cells, an enumeration of further pertinent features of plant cells follows.

In addition to nucleus and cytoplasm other organs are usually to be found in the plant cell though their presence is in no wise obligatory to maintain life. Within the nucleus one or more dark granular bodies of irregular shape are often visible which are designated as inner nuclei or nucleoli (Figure I, 1). These are thought to consist of reserve material since they disappear during cell division, again to reappear in the resting daughter nuclei. Plastids are generally present which in the majority of the higher plants are lenticular in shape and consist of somewhat denser protoplasm than the semi-fluid cytoplasm in which they are immersed. Plastids are of various types and serve different functions in plants. Chloro- (green) plastids (5) furnish the ground work in which the pigment chlorophyl is enmeshed which is of foremost importance in photosynthesis. The colors of certain fruits and vegetables such as the carrot are traceable to chromo-(color other than green) plastids. Leuco-(white) plastids are instrumental in the formation of reserve starch grains while oleo-(oil) plastids are features of certain storage cells. Plastids never arrive *de novo* but always through division of previously existing plastids. On occasion, if it suits the life economy of the plant, one type may become metamorphosed into another. For example, the cells of the young ovary wall of many flowers contain leucoplastids

which subsequently are changed into chloroplastids in the green fruit and into chromoplastids in the ripening pericarp.

Finally, there is a whole list of products which are in no sense cell organs but which are found within living or dead cells. Numbered among these are food substances such as carbohydrates (sugars, transitory and reserve starch grains, inulin, etc.), proteids either in amorphous or crystalline form (aleurone grains), and oils and fats. Often products of metabolism occur whose function in the life economy of the plant is in doubt. Among these are included tannins, organic acids, dye-stuffs, and crystals of various shapes and kinds, mostly of calcium oxalate.

The cell proper, that is, the living part which consists of protoplasm, is known as the protoplast. In plant cells undergoing division or enlargement, the protoplast occupies all the space within the wall but in older cells interstices or vacuoles (Figure I, 7) occur in the protoplasm which are filled with watery cell sap. In such mature or senile cells there is usually a peripheral or wall layer of cytoplasm which lines the cell wall. Within this are one or more vacuoles, each bounded by a plasmic membrane. The nucleus may retain its median location and continue its directive function through protoplasmic connections which extend to the peripheral layer or, as is quite often the case, become eccentric in position and imbedded in the cytoplasmic wall layer itself. Under such conditions the plastids are likewise restricted to the periphery of the cell and in some instances at least, move in response to outside stimuli, notably in the case of chloroplastids under the influence of light. When the latter becomes too bright, such plastids turn their edges toward the point of incidence, thus restricting the effectiveness of insolation.

But the protoplast of the plant cell, owing to the nature of the protoplasm of which it consists, is very delicate. It can neither withstand desiccation nor assume a rigid form and without rigidity the higher plants cannot function. To meet this need nature has designed the cell wall which is to be regarded as secreted by the protoplast and designed to afford more or less rigidity to the cell, providing as it were a room or compartment wherein the cell organs may function undisturbed. Cell walls vary greatly in shape and thickness in different plant parts to conform

to the needs of protoplasts but, aside from the fungi, there is a remarkable uniformity in their chemical composition. The basis is always the carbohydrate cellulose ($C_6 H_{10} C_5$) n with which other substances such as pectin, cutin, suberin, or the complex which is collectively designated as lignin, are associated. The World War taught us that wood which is a plant tissue could afford an ample supply of cellulose in time of need which when nitrated, produces powerful explosives.

The ontogeny or life history of a cell is best understood if it is divided into epochs though it must be understood that one epoch may overlap another. Thus we have in the order of precedence the epoch of formation, of enlargement, of thickening, and in the case of woody cells, of lignification or wall hardening. We shall consider these separately and observe their significance in the formation of woody tissue.

Cell Division.

Cells never arise *de novo* but always through division or union of pre-existing cells. All the working (somatic) tissues of plants, and animals as well, are traceable to the first source; they arise through cell division. It is only in the case of sexual cells that fusion results in the formation of new individuals and sexuality, contrary to the usual idea, was not designed to insure an increase in numbers but rather, to keep up the vigor of the race. In such a union each sex-nucleus possesses inheritable characters which are matched by characters of co-ordinate rank in the other. The dominant characters prevail in the fusion nucleus and some are drawn from each parent cell. But the stimulus derived from such a fusion may continue for generations of vegetative cells. For example, in trees produced from seed, the developing ovule on the parent tree contained a female nucleus which was fertilized by a male nucleus brought to it through the agency of a pollen grain and pollen tube. Following fusion, a whole race of cells, an untold number of them, were derived from cell division and these in the aggregate make up the mature tree as we know it in nature. Wood arises directly through cell division but indirectly as a result of cell fusion, since trees as organisms would not long survive were the stimulus of fertilization to be withdrawn prior to seed formation.

As pointed out in the preceding paragraph, the nucleus is the most important organ in cell division because it is

the "bearer of heredity." It follows that a study of cell division is largely a study of nuclear dynamics; cytoplasm and the plastids, when present, may be regarded as passive agents in the process and continue to live as well with the one as with the other daughter nucleus, though provision is made which insures the presence of these organs in each of the new cells. Details of nuclear structure and division can only be deciphered in cells that have been properly killed and stained and it is customary to treat plant tissues with chemicals to bring this about. The technique is elaborate but affords satisfactory results if the material is happily chosen.

Cell division may be direct* or indirect. The first is found in the lowest primitive plants or in senile vegetative cells that have nearly ceased to function. The nucleus becomes dumb-bell shaped and divides through simple fission. As annular thickening is formed meanwhile within the old cell wall and medium to the ends of the nucleus and through the extension of this centripetally a new wall results. In by far the majority of cases indirect division takes place and Nature has invented a very ingenious method to insure the halving of nuclear material between the daughter nuclei. The result is a number of nuclear figures which follow one another in regular sequence the interpretation of which requires an understanding of the intimate details of nuclear structure.

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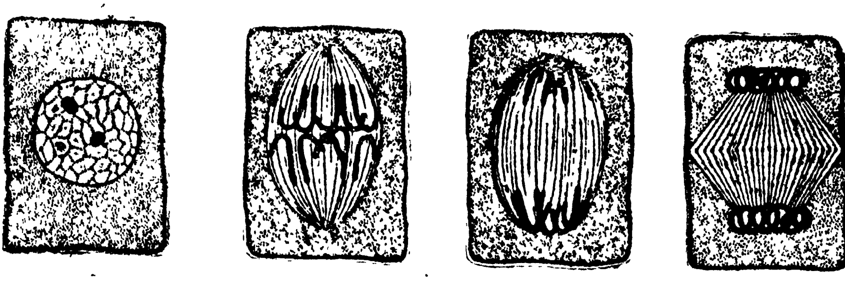
Figure II.—Fours stages of indirect vegetative division. A. Typical resting cell, B. Nuclear spindle and chromosomes; the latter have split longitudinally and halved chromosomes are passing to the respective poles; C. Halved chromosomes at the poles of the nuclear spindle; D. Beginning of the formation of the daughter nuclei. The spindle fibres have started to thicken at the equator of the spindle to form the cross-wall.



A B C D

* Direct division is designated as "amitotic," indirect division as "mitotic" or "karvokinetic."

The resting nucleus (Figure II, A) is sharply delimited from the surrounding cytoplasm by the nuclear membrane which is to be considered as a product of the cytoplasm. Within this and bathed with nuclear sap is the nuclear reticulum consisting of delicate threads (linin threads) which anastomose in a net-like manner and in which lie granules which stain readily and are consequently designated as chromatin granules. One or more larger bodies are often present at the intersections of the linin threads, the so called nucleoli.

The first evidence of indirect vegetative division is to be noted in the contraction of the nuclear reticulum to form a more or less convoluted ribbon or spireme. This subsequently segments into a number of " U " or " V " shaped pieces which have been named chromosomes.† Meanwhile the nucleoli and nuclear membrane disappear and a nuclear spindle consisting of equator and two poles is formed out of fibres. The chromosomes become aligned at the equator and each splits longitudinally (the long way) into daughter chromosomes (Figure II, B). Traction fibres become attached to these and, as they contract, pull the daughter chromosomes to opposite poles (Figure II, C) where they again organize resting nuclei (Figure II, D). Meanwhile the nuclear spindle has thickened at the equator and a new cross wall develops between the resting cells. The final result is two daughter cells which have arisen from a parent through division, each with a nucleus containing the same number of chromosomes as the mother cell.

The type of indirect division described briefly in the preceding paragraph is responsible with minor modifications for the tissue which we know as wood. It is characteristic of the growing points of trees, both apical and lateral, which are the ultimate source of wood. Every one of the millions of cells which make up the mature tree stem results in this way. It is only in the formation of seeds in trees that indirect reduction division takes place, for seed formation is the result of a sexual act, the fusion of sex-nuclei. Were Nature to make no previous preparation, the chromatin material and chromosome number would be doubled through such a fusion. This eventuality is avoided in that a halving of the chromosome number occurs in

† The number is constant in a given species of plant or animal.

advance in the formation of germ cells (gametes) through indirect reduction division. The latter differs from indirect vegetative division in that chromosomes become aligned in pairs at the equator of the spindle. The traction fibres pull "whole" chromosomes to the respective poles with a resultant halving of the number in the daughter nuclei. Sexual nuclei are usually born in fours (tetrads) because the reduction division is followed immediately by a vegetative division the significance of which is still unsolved. Upon the fertilization of an egg cell containing the half (haploid) number of chromosomes in the body of an ovule by a sperm cell from a pollen grain with a like number of chromosomes, the normal or diploid number is restored in the developing embryo within the seed. For comparison the details of indirect vegetative and indirect reduction division are shown diagramatically in Figure III.

Cell Enlargement.

The second epoch in the life history of an individual cell is that of enlargement and cells vary remarkably in the extent to which this takes place. In some cases there is little change either in shape or size following origin through division; the cell thickens its wall somewhat and becomes a corporal part of the mature tissues. As a rule, however, there is an increase in dimensions and enlargement from a few to several hundred times takes place. In individual cells such as are found in unicellular plants, growth may continue over the whole surface of the wall and result in an individual which is a replica of the original unit except in size. In cell aggregates to the contrary, that is, in tissues, enlarging cells no longer act as units; they often exert considerable pressure upon one another and mutual adjustments must be made. In such instances growth may be confined to given areas of the wall and the adult form may assume quite a different shape from the juvenile cell which gave it birth. For example a mature cell may be concerned with the conduction of food in a given direction as radially in a tree or up the stem and the plant finds it economical to elongate it in the direction of the food stream. Examples of this are found in the wood ray cells where the extension is radial, or in the longitudinal wood elements which course vertically between rays and which serve while a part of the sapwood as conductors

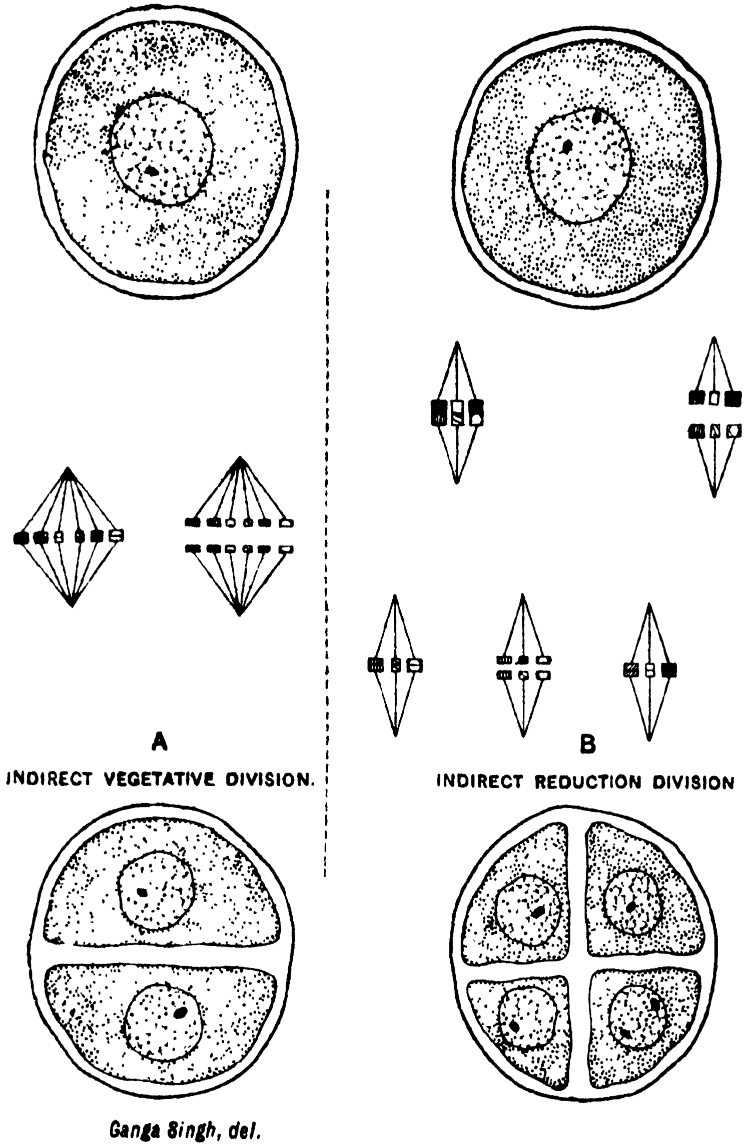


Figure III. --Diagrammatic illustration showing indirect cell division. A. Indirect vegetative division. B. Indirect reduction division. Reduction division in "B" is followed immediately by an indirect vegetative division and a cell-tetrad results.

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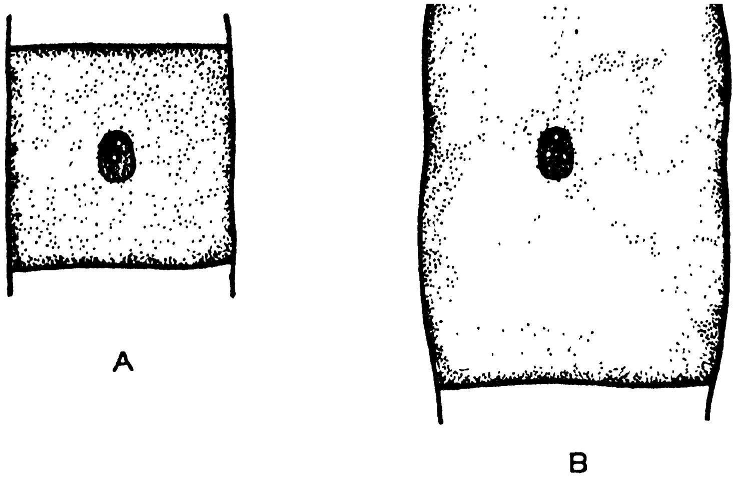

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Figure IV.—A. A cell which is completely filled by its protoplast. B. The same after enlargement and the formation of vacuoles filled with cell-sap.

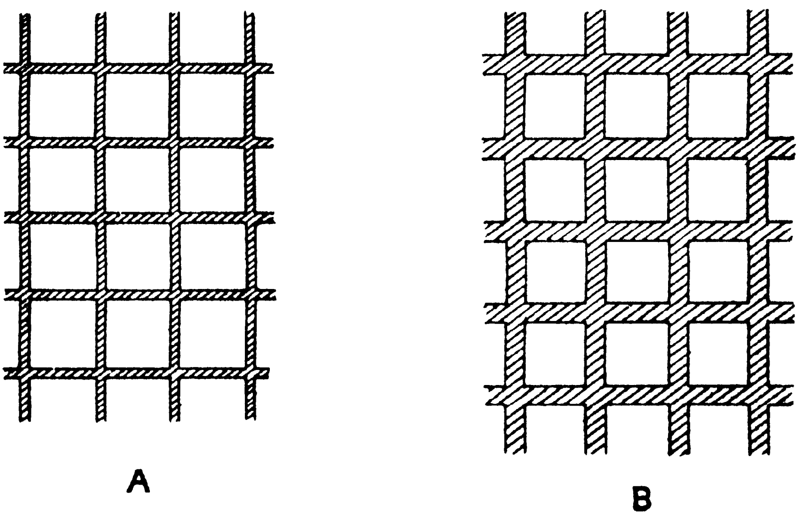

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Figure V.—Diagram to illustrate the "supposed" structure of the primary cell-wall. The squares represent ultra-microscopic particles of wall-substance separated by films of water. A. Wall of a cell lacking turgor. B. Wall of a turgescent cell.

of sap up the bole of the tree; such vertical elements are greatly elongated and may on occasion (fibres) become one hundred and fifty or even more times as long as they are wide.

Water plays a very important rôle in cell enlargement and tissues which are growing rapidly are always fluxed with it. The reason for this is explained in that plant cells, as they enlarge, develop vacuoles (Figure IV) which act as reservoirs for cell-sap.* The cell is no longer filled by the protoplasm as it was in the embryonic condition since the protoplast fails to keep up with the increase in volume. This constitutes one of the chief differences between plant and animal cells for in the latter the protoplast usually continues to fill the entire cell cavity. As the enlarging plant cell approaches its final size, the vacuoles become larger and often coalesce until finally the protoplasm may be restricted to a parietal layer lining the cell wall in which the nucleus is imbedded, or the latter may retain its median position in the cell and be attached by strands to the peripheral layer of protoplasm.

Growth and the origin of vacuoles in the cell are traceable to osmotic pressure. As was pointed out on page 15 the protoplast develops a membrane of ectoplasm on its outer surface which separates it from the cell wall (cellulose wall) and this possesses osmotic properties. In addition each vacuole is bounded by a layer of endoplasm which exhibits similar characteristics. Within the cell sap are various organic acids and their salts in dilute solution and these, with certain crystalloid substances, are responsible for osmotic pressure. The cell is enabled to absorb water from without its walls and to store it in vacuoles. The latter enlarge further, the peripheral portion of the protoplast is pressed firmly against the cell wall and turgor results. The primary cell wall is stretched and increases in area to accommodate itself to the pressure from within; in other words, it grows. It follows that cell size is restricted within certain limits because the formation of vacuoles cannot continue indefinitely when the protoplast ceases to grow. The large cells which feature certain plants or plant parts owe their origin either to further growth of the protoplast as the cell ages or to initial embryonic cells of large size.

* Cell sap consists largely of water.

The manner of the increase in the surface area of the primary cellulose wall has been the subject of investigation and may best be explained if a supposition is entertained as to its ultra-microscopic structure. We may conceive it as consisting of layers of millions of ultra-microscopic particles, groups of molecules or miscellae as they have been termed, which exhibit mutual attraction for one another but are separated by thin films of water. (*See* Figure V*.) When turgor results, that is, when there is pressure from within, the wall is stretched, the miscellae become more widely separated and the films of water increase in width. Eventually new miscellae are interpolated between the old in the wall by the protoplast, working from within the cell cavity, and the surface area is thereby increased. While the "intussusception" theory is based wholly on supposition, it offers a means of explaining logically areal growth in primary cell walls

Cell-Wall Thickening.

Cell thickening or better said, cell wall thickening, takes place from within the cell and the new layers are to be considered as the excretion of the protoplast. A necessary corollary to this statement follows, namely, that wall thickening proceeds only in living cells; where the protoplasts have disappeared there can be no further addition of cell wall substance.

There are two theories which seek to explain the thickening of cell walls, namely, the "apposition" theory and that of "superposition." In the first ultra-microscopic wall particles (miscellae) are deposited separately and individually upon the pre-existing wall surface (primary wall) and secondary layers are gradually formed by deposition. This process has sometimes been likened to that which occurs in the electro-type process of plating where metallic particles are deposited on a metal surface through the agency of an electric current. Owing to the ultra-microscopic nature of the particles of wall substance, there can be no visual evidence in support of this theory.

In favourable material it is sometimes possible to distinguish stratification in walls, especially in cross sections of bast fibres. This would seem to substantiate the "su-

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* Spiral structure is not evident in primary cell walls.

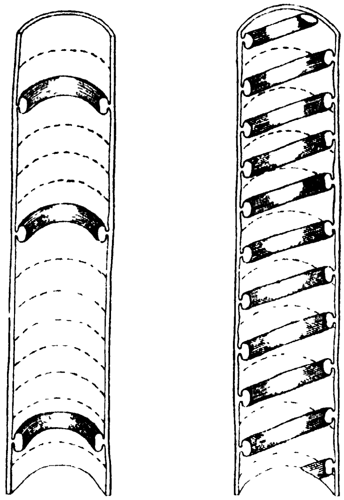

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Figure VI.—Vessel-segments with annular and spiral thickenings.

Photo. Zinco., August, 1925.—No. 3289-6-2000

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perposition " theory, that whole layers of cell particles or lamellae are deposited at a given time from within the cell. An analogous condition is found in grains of reserve starch which are formed within cells. For example, in starch grains from the potato tuber, definite bands of concretion can be detected upon staining with iodine, and the hilum or centre is often eccentric.* Possibly both apposition by " particles " and superposition by " layers of particles " take place and wall thickening is the result of a combination of these processes.

The epochs of cell enlargement and cell thickening may proceed at the same time and especially does this hold true where thickening is localized and restricted to certain parts of the wall. Vessels with annular and spiral thickening are not uncommon in plant parts which were undergoing rapid extension as the tissue matured. Such elements are frequently found coterminous to the pith in stems, in the vascular bundles of bamboo and other grasses, and elsewhere (Figure VI). The cell wall remains thin between the rings or spirals and the cells still continue to elongate after localized thickening is well under way. Furthermore, it is quite plausible to conceive of " intussusception " and " apposition " or " superposition " as going forward at the same time; in other words a certain amount of generalized thickening may occur while cell enlargement is still in progress and this certainly takes place in many cases. The epochs of cell growth and cell thickening undoubtedly overlap.

In the majority of cells, thickening becomes general sooner or later and secondary and even tertiary layers are deposited upon the initial layer (middle lamella) which separated the cell originally from its neighbours. All degrees of thickening are found in the various cell types. Conductive and storage cells usually remain comparatively thin walled, that is, with a conspicuous cavity or lumen: mechanical cells on the contrary are usually thick walled and the cell cavity may be reduced to a mere slit Familiar examples of the last are found in the strengthening fibres of the bast in many trees and these in addition often exhibit layering of cell wall substance as well.

Thickened cells still retain their mutual dependence upon one another where they are found in the aggregate,

* Starch grains are solid and it follows that deposition is from without that is, centrifugally.

that is, in a tissue. They remain in communication through the agency of pits which are thin places in the wall (not perforations) and in some cases at least, by strands of protoplasm (plasmodesms) which extend bodily through the wall and connect protoplasts. Pits are conspicuous structures of thick walled cells and result from the fact that the secondary and tertiary thickening layers of cell walls are interrupted at certain points leaving the initial layer (primary lamella) exposed and that similarly, gaps arise opposite these on the other side of the middle lamella in the secondary layers of abutting cells. A pit results, an interruption in the secondary wall layers of coterminous cells, spanned by the original middle layer (lamella) of the wall.

Pits fall naturally into two categories, the "simple" and the "bordered," whose structure may be understood by reference to Figure VII. In the simple pit as seen in sectional view (Figure VII, 3), the secondary layers are abruptly terminated at the pit canal and the latter is bounded by nearly parallel sides and is usually restricted in diameter. When viewed in surface aspect such pits appear as dots or slits of regular or irregular contour. Simple pits are characteristic of manufacturing and storage tissues (parenchyma) and may be scattered over the cell wall, the latter then appearing punctate, or grouped in definite fields.

The bordered pit (Figure VII, 1) is a feature of some conducting and of mechanical cells, and is of more specialized structure. The pit orifices on opposite sides of the primary lamella are comparatively small and open into a roomy pit cavity or court, a condition which arises through overlapping of the successive layers of thickening in the walls of coterminous cells. The court of the pit is spanned by the primary lamella which in typical pits* is thickened through the median region to form a plug or torus. On occasion the latter may act as a valve and through the stretching of the unthickened part of the primary lamella be pushed either to the right or to the left hand wall, effectually closing the pit orifice.

In surface view typical bordered pits are orbicular in outline and owing to the fact that cell wall substance is

*The bordered pits of coniferous woods are invariably provided with a torus but in dicotyledonous woods it is usually wanting

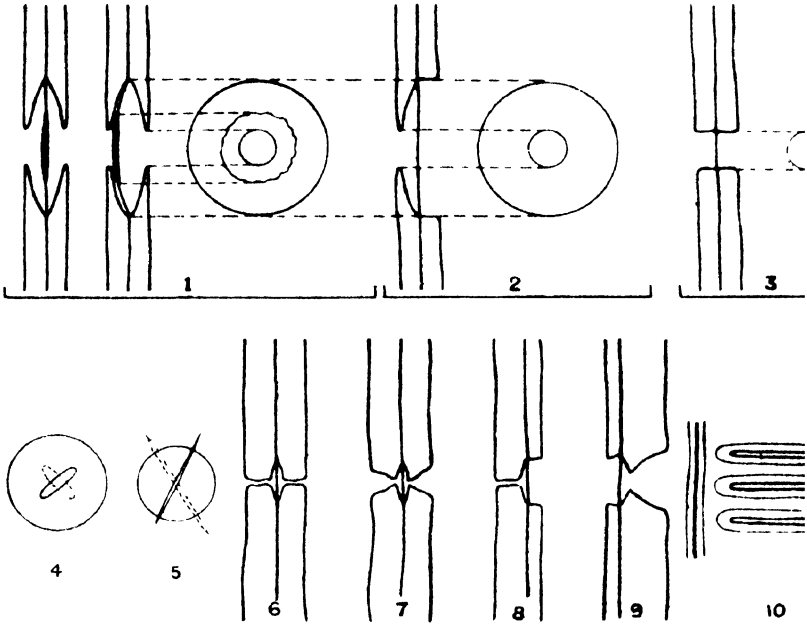

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Figure VII.—Schematic drawing illustrating the various types of pits. (1 bordered pit in sectional and surface views ; (2) Semi-bordered pit without t sectional and surface views ; (3) Simple pit ; (4 and 5) Types of pits fou on narrow prosenchymatous elements, surface views ; (6, 7, 8, 9) Types of pits frequent in dicotyledonous wood, sectional views ; (10) Scalariform bordered pits which often are found on vessel segments with scalariform perforations.

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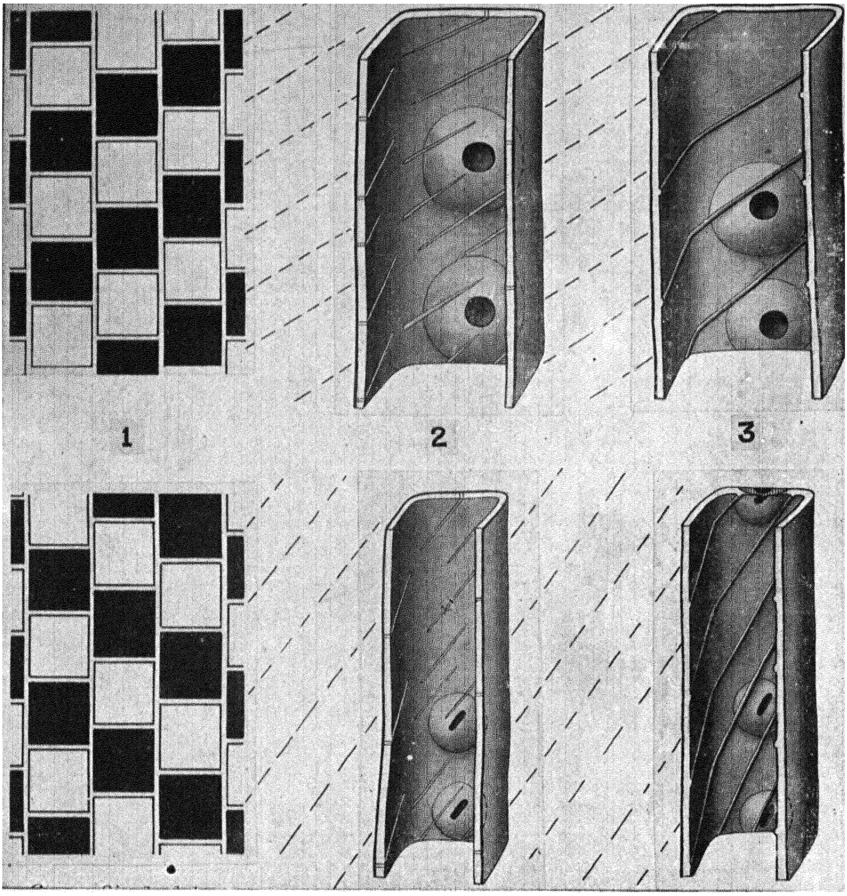

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Figure VIII.—Diagrammatic drawing illustrating the spiral structure of the secondary layers of tracheid walls. (1) Spiral arrangement of ultra-microscopic wall particles in secondary wall; (2) Microscopic checks in secondary layers of cell-wall; (3) Spiral thickening bands on the inner face of secondary wall.

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translucent and that microscope lenses have "depth of focus," three concentric circles can generally be distinguished, the median one of somewhat ragged contour (Figure VII, 1). They are to be explained in that the smaller (inner) circle represents the orifice leading into the pit cavity (on the side toward the observer), the outer circle the limits or boundary of the pit cavity at the primary lamella, and the median circle of ragged contour the torus, the thickening of which thins out unevenly at the margin. Bordered pits, owing to their size occasioned by the relatively coarse texture of the wood, are characteristic structures of the longitudinal cells of coniferous timbers. They are widespread and very numerous as well in the wood of dicotyledonous trees but are much less conspicuous because of their restricted dimensions.

Various modifications of the bordered pit occur, in part traceable to the ultra-microscopic structure of the cell wall. As explained in the preceding paragraphs the secondary layers are to be considered as consisting of extremely small particles which are added by the protoplast either individually or in layers. A further definite alignment of these is to be suspected owing to the behaviour of the cell wall; they appear to be arranged in spirals* which ascend from right to left (*see* Figure VIII, 1). Evidence of such alignment is forthcoming where microscopic checks are formed in the thick walls of woody cells through the air or kiln seasoning of timber (Figure VIII, 2). In wide lumened cells such checks ascend in a relatively low spiral while steep spirals are features of extremely thick walled narrow lumened units.† Furthermore, spiral tertiary (inner) thickening bands are sometimes present in special cases and the same rule applies in this instance, (Figure VIII, 3). Spiral wall structure has no appreciable effect on bordered pits where the element concerned is wide lumened. In narrow cells on the contrary the pit orifice is stretched obliquely to conform to the spiral in the wall and may, in extreme cases, extend beyond the limits of the pit cavity (at the primary lamella) as a narrow slit. In such pits, an "X" figure is often observed because the wall spiral

* There is no evidence to indicate spiral alignment of particles in the primary cell wall (primary lamella).

† It follows that in one and the same cell wall the steepness of the spiral may increase. In thick walled, narrow lumened elements, the greatest ascent is registered in the layers immediately coterminous to the cell cavity.

ascends in opposite directions in the secondary layers which are situated on different sides of the primary lamella* (*see* Figure VII, 4 and 5).

In conclusion the salient points of cell thickening may be summed up as follows. Cells thicken from within and while the protoplast is still living. Wall particles (miscellae) are added either as individuals (apposition) or in layers (superposition), possibly in both ways. Cell thickening, especially localized thickening, may proceed while cell enlargement is still in progress; the cell epochs of enlargement and thickening overlap. Pits, both simple and bordered, are features of thickened cell walls and facilitate inter-communication between elements. The secondary and tertiary layers of cell walls exhibit evidence of spiral structure and the spirals become steeper in narrow lumened cells and as the lumen is approached in one and the same wall. Narrowed pit orifices tend to conform to the spiral of the wall in which they occur.

Cell Hardening (*Lignification*).

The final epoch in the ontogeny of the woody cell may be designated as that of wall hardening or lignification. Lignification is a characteristic feature of the woody part of vascular tissues but it is in no wise confined to such tissues. Nor is lignification a necessary part of the life cycle of every cell; many remain entirely unlignified throughout their whole existence and consist wholly of cellulose; for example the walls of sieve tubes are never lignified and the same may be said of the majority of epidermal cells, though the guard cells of stomates become woody in certain plants. In other cases a water-proofing process comparable to that of lignification takes place whereby the cell walls become infiltrated with cutin (cutinized) as in the outer walls of the majority of epidermal cells or with suberin (suberized) as in the layers of periderm (cork) which take over the protective function in stems and roots following the disappearance of the epidermis.

The basis of cell wall substance is cellulose,† but cellulose walls do not afford marked rigidity. In small plants or succulent plant parts, the organism often depends on turgor

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* One such layer is toward the point of observation as viewed with the microscope, the other on the opposite side of the middle lamella away from the observer.

† The fungi present an exception.

pressure alone to insure the requisite firmness. This is well illustrated in the stalks of flowers which wilt after being plucked from the parent stem and in which there is not sufficient lignified vascular tissue to afford the necessary mechanical support. But the force of turgor has but narrow limits of application; the higher plants have been compelled to devise other means to insure mechanical strength in their stems, stems which in the case of trees, are often a hundred or more feet high. Nature has met this need through lignification;* through lignification cell walls are rendered harder, stronger and more durable than those of pure cellulose.†

The term "lignification" was coined to designate wall hardening of woody cells because originally lignin was thought to be a definite organic compound which became infiltrated into cellulose walls and to which a definite chemical formula was assigned. Modern science has dissipated this idea; lignin is rather a complex of a number of allied organic compounds in close association with each other. Undoubtedly the lignin of all cell walls will be found to have compounds in common but it may well be inferred that some of its minor constituents at least, vary somewhat in different plants.

The relative amounts of cellulose and what is designated as lignin in lignified cell walls is difficult to determine analytically. We may delignify woody tissue with chemicals (as is done in the paper industry) and fix upon the amount of cellulose that is left. The cellulose content of wood is found to vary between 45 and 55 per cent.; approximately 25 per cent. of the material removed in the delignifying process consists of lignin which is always accompanied by carbohydrates of various sorts while a small amount, usually less than one per cent., is mineral matter Whether this

* There is evidence to indicate that the lignified walls of the fibrous constituents of wood are further stiffened by the addition of sparingly branched, non-hygroscopic rods of silicified material which extend longitudinally from one end of the cells to the other. See Brown, F. B. H., The Silicious Skeleton of Tracheids and Fibres. Bul Torrey Bot Club, 47 : 407-424, 1920

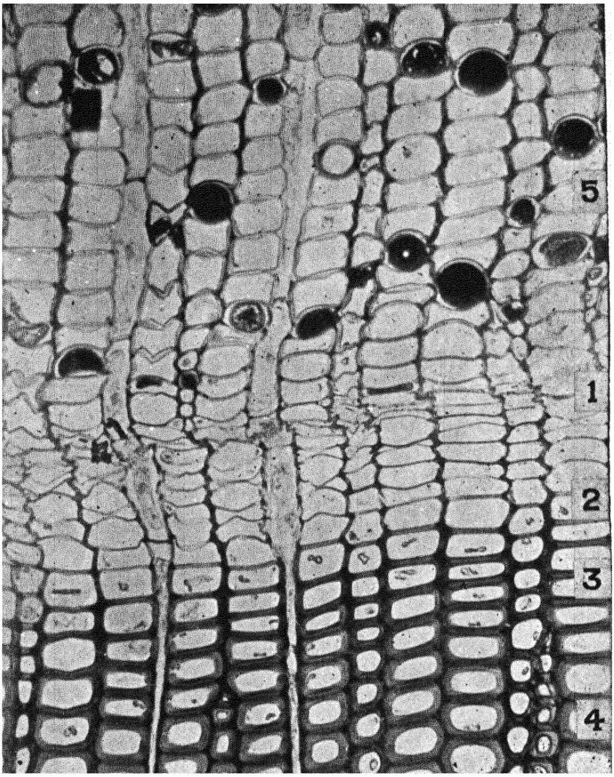
† There is no direct evidence that cell walls are rendered more permeable through lignification The cellulose wall prior to lignification does not exhibit osmotic properties; unlignified cells become turgid not through the semi-permeable character of the cellulose wall, the excretion of the protoplast, but rather owing to the osmotic properties of the ectoplasmic membrane surrounding the protoplast and the endoplasmic membranes about the vacuoles In turgid cells the protoplast exerts pressure on the passive cellulose cell wall which surrounds it Pits and pit membranes in thickened walls but facilitate the passage of solutes through a wall which is in no sense semi-permeable.

same rough proportion holds good for the walls of all lignified cells irrespective of their position in the plant can only be conjectured; there is no reason to infer otherwise.

We have seen that the physiological significance of lignification is undoubtedly to enhance the mechanical strength (rigidity) of cell walls. It remains to point out the relation of the protoplast to the lignifying process and to cell ontogeny. Lignification, like cell thickening, proceeds only so long as the protoplast continues to live. it is the result of vital activity and is to be regarded as a peculiar chemical and physical readjustment in cell wall substance traceable to living protoplasm. Dead cells cannot further lignify their walls. Moreover, lignification is to be regarded, at least when it is general throughout the cell wall. as evidence of cell maturity, though not necessarily of cell senility. Once lignification becomes general, cell enlargement ceases as the one process precludes the other. It is only in localized lignification that growth may still continue in cellulosic portions of the cell wall—a condition well illustrated by the lignified bands of annular or spiral vessels. The wall between such bands consists of cellulose and potentially at least, is capable of further areal growth.

In by far the majority of woody cells lignification is initiated during or immediately after wall thickening. (Figure IX). The two phenomena often overlap as lignification may be progressing vigorously in the primary and secondary layers of the wall, more particularly the latter*, while the protoplast is engaged in depositing a tertiary wall layer from within. As a rule the protoplasm disappears from woody cells immediately following lignification; the process does not appear to encourage the longevity of protoplasts though exceptions to the rule occur, notably in the case of wood parenchyma cells which may retain their protoplasm for many years, in fact as long as they are a part of the sapwood. It is not uncommon to find cells in which wall hardening in the tertiary layers appears to have been arrested by too rapid cell necrosis and the latter consist largely of cellulose which often exhibits highly hygroscopic properties and gives rise to the gelatinous elements of woody tissue. The gelatinous fibres of the legume

* The secondary layer receives the bulk of the lignification though appreciable amounts of lignin are found in the primary wall. The latter responds differently to reagents and stains owing to the presence of other compounds within it, pectin substances possibly.



Photomicrograph by H. P Brown.

Figure IX.—Photomicrograph of a cross section through the cambium (*Pinus longifolia*) while growth was in progress. (1) Cambium; (2) tracheids undergoing thickening and lignification (3) the same, a later stage; (4) tracheids complete as to thickening and lignification; the protoplasts have disappeared; (5) functioning unlignified phloem consisting of sieve tubes, phloem parenchyma cells, and wood rays.

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and Anacardium families are very numerous and often have a direct bearing on the utilisation of wood for certain purposes. Such timbers tend to check less readily upon drying because they cling to their moisture content.

Examples of delayed lignification in cell walls are not wanting as it does not invariably accompany or immediately follow wall thickening. The phloem parenchyma cells of many trees continue to live and function for many years after the crushing of the sieve tubes with which they are associated and eventually may become lignified as they are pushed further toward the outside of the tree by the formation of new tissues beneath them. The corollary follows that any living cell, potentially at least, is capable of lignifying its wall under the stress of new or unusual conditions. Cells which are a corporal part of the wood of a tree are peculiar, however, in that they lignify their walls as soon as they attain their maximum size; lignification may proceed while thickening is still in progress.

In summation it should be noted that lignification was undoubtedly devised by nature to render cell walls firmer, harder, and more durable but not necessarily more permeable. Lignin is not a definite organic compound but a com plex of compounds. Lignification, like wall thickening, proceeds only in cells with protoplasts and may be initiated in the primary and secondary layers of the wall while thickening is still progressing in the tertiary layers. The epochs of thickening and lignification may overlap; not so that of enlargement. Once lignification becomes general in a cell wall, further increase in the size of the cell is precluded. In the formation of woody tissue, wall hardening follows wall thickening very quickly. Delayed lignification may result in special cases since any living cell is potentially capable of initiating the process. Lignified cells usually lose their protoplasm quickly and the process does not appear to encourage longevity of protoplasts. Such dead cells, however, may still continue to participate in the physiological activities of the plant.

PART IV.

Cell Aggregates or Tissues.

Origin of Tissues.

The study of the cell as an individual is called cytology, the study of cell aggregates, that is, of tissues is designated as histology. Since wood is a cell aggregate of a specialized sort, an understanding of tissues in general and of their classification, is desirable ere proceeding to a detailed study of wood structure.

It is difficult to coin a definition for a tissue though various attempts have been made. For example tissues have been defined as groups of cells of similar shape, common origin, and common function, in intimate association. But wood is a tissue and the cells which compose it vary decidedly in shape as will be pointed out in the pages which follow. Furthermore, those immediately coterminous to the pith have a different origin than those subsequently formed, namely, in the growing tip of a twig and in a lateral cambium respectively. And to wood or to certain cells thereof different functions are delegated. Rather, tissues are composed of working aggregates of cells which, owing to their close communion, generally exhibit a certain degree of uniformity not only in respect to the functions which they perform but also in the several structural modifications which are of necessity correlated with these. It is quite impossible to restrict the definition further; such a general statement must suffice.

Tissues arise through cell division and the manner of this determines the orientation of their cellular constituents. When the divisions are all in one plane, a row of cells is produced and a filamentous form is the result. Many of the pond scums are simple plants of this sort and assume the shape of green threads Where the divisions are in two planes, a plate of cells is formed; if in three planes masses of cells are produced in three dimensions which make up the body of the adult individual. All these types are represented among the lower simple plants (Thallophytes and Bryophytes) but in vascular plants

three-plane division is the rule; their stems, leaves, and roots exhibit thickness.*

In the simplest of the non-vascular plants, cell division is not restricted to definite points. Any cell is capable of division, potentially at least, and growth through division may ensue at any place throughout the body of the organism. As evolution and division of labour advanced, certain units were set aside as growing points and retained their ability to divide; such cells were either restricted to the apices of the organism or exceptionally, became intercalary. Forms of this type are undoubtedly more specialized and plants with such unicellular growing points are in existence at the present time. In fact growing points of a single cell are features of the Thallophytes, Bryophytes, and the true ferns of to-day. It is first in the club mosses, " fern allies," that multicellular growing points appear and as seed plants were evolved they continued as constant features of these modern organisms. The growing points of seed plants are multicellular though not of necessity restricted to apices, and consist of numbers of embryonic cells.

Multicellular growing points are composed of meristem, that is, of meristematic or embryonic cells which have certain features in common. Numbered among these are their relatively thin unlignified walls, comparatively large nuclei, and richness in protoplasm; the protoplast occupies the whole interior of the cell and vacuoles are wholly wanting. Such meristematic cells retain their ability for repeated division, are consequently quite undifferentiated, and possess few of the attributes of mature units. They are very delicate and subject to desiccation and nature has designed various means to protect them such as overlapping embryonic leaves, root caps (calyptrogens), and bark.

Classification of Tissues.

The tissues that arise from undifferentiated meristems are classified in various ways from the stand point of origin, form, or function. The following classifications should appeal most to the student of wood anatomy.

* The lower simple plants exhibit a remarkable variation in the interdependence of the cells which make up their tissues. Some, as *Pediastrum*, are true coenobia, groups of individuals which are individuals in every sense except that they are held together loosely in the same cell plate. Other Thallophytes show more specialization; their cell aggregates are tissues in the true sense since there is a decided division of labour and to certain tissues specific functions are assigned Mutual dependence between cell aggregates has resulted.

On the basis of origin we may speak of primary and secondary tissues. Primary tissues arise only from apical meristems; lateral meristems give rise to secondary tissues. Thus in a tree growth in length (primary growth) is traceable to the apices of twigs and roots; growth in thickness results from a lateral meristem (cambium) which underlies the bark and which through cell division provides for increase in thickness. Such lateral meristems are features of coniferous and dicotyledonous trees but are wanting in the palms, bamboos, and other monocotyledons. In the latter, growth in thickness is usually traceable to primary (apical) growth which continues over a number of years.

Tissues may be divided into fundamental, vascular, and tegumentary according to function. Fundamental tissues consist chiefly of manufacturing and storage cells. The green mesophyll of the foliage leaf well illustrates this type since it is in such green cells that photosynthesis proceeds. Vascular tissues are in the main conducting and mechanical tissues. They are represented in the leaf by the veins which conduct water and mineral solutes in dilute solution into the leaf and elaborated food, chiefly in the form of sugar, out of the leaf into the leaf-stalk and eventually into the parent stem; in addition leaf-veins act as "stays" and perform a mechanical function. Tegumentary tissues are covering or epidermal tissues whose function it is to protect underlying delicate parts from desiccation. The outer cell wall of epidermal cells is cutinized as a rule and thereby rendered less penetrable to water and gases. The epidermis covers both upper and lower surfaces of a foliage leaf but minute breathing pores or stomates are present, at least on the side away from the sun. Tegumentary, fundamental, and vascular tissues are present in other plant parts aside from leaves and their position in the tree stem will be discussed at some length further in the text. Wood as we find it in the tree is wholly vascular but the reverse does not apply; all the vascular tissue of the tree stem does not become a corporal part of the woody cylinder as the inner bark arises from the accumulation of phloem.

A third tissue classification that is most convenient in a discussion of wood anatomy is that of parenchyma versus prosenchyma. The basis of division here is rather that of function. Parenchyma consists of cells which as a rule are

relatively thin walled, retain their protoplasts for some time (often a number of years), are not greatly elongated in any one direction, possess simple pits, and conduct and store carbohydrate food. Prosenchyma in contrast consists of thick walled, dead cells which are usually greatly attenuated in a given direction, possess bordered pits, and have as their paramount functions water conduction and the insuring of mechanical strength. Both parenchymatous and prosenchymatous cells are present in wood and will be discussed in detail under "wood structure."

Other tissue classifications have been coined to meet the need of physico-anatomists in the field of plant physiology but an elaboration of them in an elementary treatise of this type would but lead to confusion. In additon there is a decided lack of uniformity in the usage of terms and the interpretation of the limits of the same. The student who would pursue the subject further is referred to the larger botanical texts which deal with plant physiology and physiological anatomy.

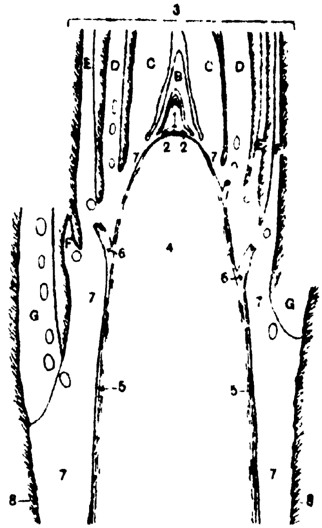
Primary versus *Secondary Thickening in Trees.*

As was pointed out on page 30, trees grow in two ways, in length and in thickness. Growth in length is due entirely to primary growth which is traceable to the apices of roots and twigs; as the various tissues which originate through cell division in these apical meristems mature and are left behind by the growing point, a certain amount of primary thickening takes place which is traceable not to repeated cell division in the ageing tissues but rather to the enlargement to their final size of embryonic cells formed at the apex. Continued growth in thickness on the other hand, that is, secondary growth, results from the activities of a lateral meristem (cambium) which, while it originated in the vegetative cone, remains undifferentiated and soon becomes lateral and annular in the stem and separates bark and wood. Secondary thickening begins the first year and the peripheral portion of the first seasonal ring is a result of it. Once activated it may continue for years, in fact for centuries in certain long-lived tree species and through its activity the woody stem is gradually built up through the accumulation of woody tissue. Trees as contrasted to herbaceous plants are organisms in which lignified tissue accumulates.

When accumulative growth proceeds in the usual way, that is, through the activities of a cambium underlying the bark which forms wood centripetally (toward the pith) and bark centrifugally (away from the pith), normal secondary thickening results. Such thickening is a feature of all trees which are a source of wood commercially. But exceptions occur among dendroid plants in that thickening may be of the anomalous or abnormal sort and here various types have been evolved. In some of the Cycads, the cambial ring functions for a time in the usual way and is then replaced by another, concentric to the first outside in the bark. The process may be repeated a number of times and sections of such stems exhibit a series of rings comparable to those visible in cross sections of the garden beet; a similar layering is found in *Dalbergia stipulacea* of the eastern Himalayas and Burma, where the bark inclusions are annular or more rarely, spiral. Or the cambium may throw off complete vascular strands (of xylem and phloem) centripetally along with a certain amount of ground tissue, and thickness accrue in this manner, a feature of monocotyledonous *Dracæna* stems. The Indian tree *Aquilaria Agallocha* which is the source of the so-called "Eaglewood" of commerce, presents an interesting variation from the normal type since inclusions of phloem are found within the wood, the result of unusual behaviour on the part of the lateral cambium. In fact many modifications of thickening are to be found which are features of certain plant families (*Menispermaceæ* and *Nyctaginaceæ*), or result from a peculiar habit (many lianas) which woody plants have assumed. Timber trees without exception possess normal secondary thickening and build up thickened stems through accumulative growth of the usual type. It is fortunate that this holds true, for the economic development of man is due in no uncertain measure to the utilisation of wood in its many forms.

Greater clearness is attained as to the procedure of normal secondary thickening in trees if the various changes which take place as the mature stem develops from an apical meristem are traced at length and in order of their precedence.

Figure X, A, represents a longitudinal section of an apical meristem in a twig of teak, overtopped and protected by embryonic scale leaves in various stages of unfolding.



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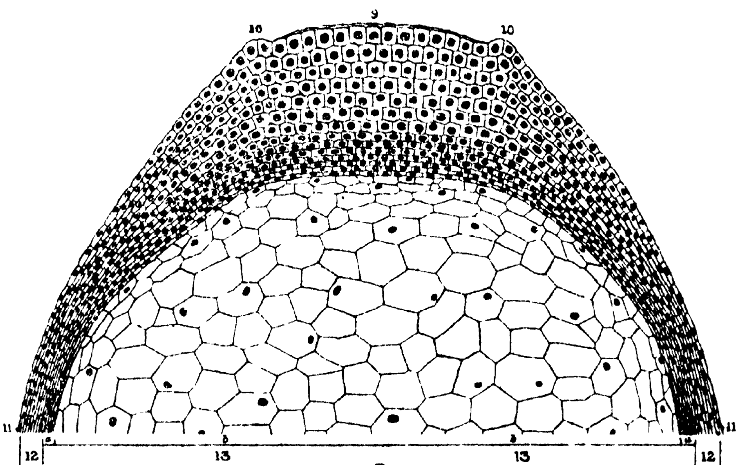

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Figure X.—Schematic drawings illustrating the apical growing point of teak (*Tectona grandis*) A (1), Apical growing point ; A (2), Lateral leaf growing points ; A (3, a, b. c, d. e, f, g), Leaves in various stages of unfolding ; A (4), Pith ; A (5), Primary vascular tissue ; A (6), Leaf-trace ; A (7), Primary cortex ; A(8), Epidermis. B (same enlarged). B (9), Apical growing point ; B (10), Lateral leaf growing points ; B (11), Dermatogen ; B (12), Periblem ; B (13a). Primary vascular tissue ; B (13b), Pith.

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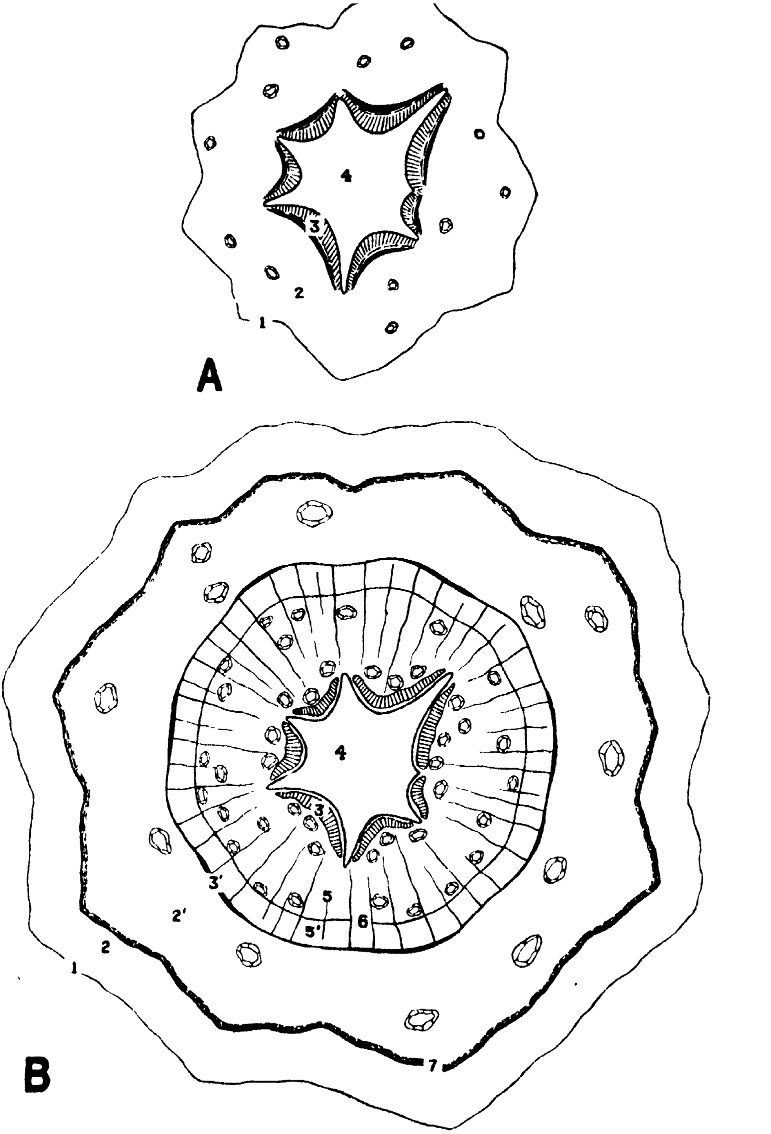

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Figure XI.—Schematic drawing of cross sections of a young twig of *chir (Pinus longifolia)* prior to (A) and following (B) secondary thickening. A (1), Epidermis ; A (2), Primary cortex ; A (3), Primary phloem and xylem (wood) separated by fundamental tissue ; A (4), Pith. B (1), Epidermis ; B (2-2′), Primary cortex ; B (3), Primary wood ; B (3′) Primary phloem ; B (4), Pith ; B (5), Secondary wood ; B (5′), Secondary phloem ; B (6), Cambium ; B (7), Periderm (cork layer).

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Since teak is a seed plant and seed plants have evolved multicellular apical meristems, the apex of the vegetative cone (Fig. X, B) consists of a number of embryonic cells which present the usual features of meristem, that is, large nuclei, absence of vacuoles, and thin walls. Such cells through three-plane division are giving origin to tissues which, as they mature, form the young twig. We may compare the conditions in force to those of a comet where the growing point is the comet itself and the maturing twig-tissues the comet-tail; enlargement (primary thickening) and differentiation of the tissues take place as they are left farther behind by the apex of the cone. A short distance back from the tip we may distinguish cells which are to initiate the three tissue systems, namely, the tegumentary, the fundamental, and the vascular. The layer of cells which covers the cone is designated as dermatogen (11) which means literally " to beget epidermis " and to this the tegumentary system is traceable. The central core of cells in which the vascular cylinder or stele (column) and pith originate (13) is known as the plerome. Separating these are a number of cells layers which are designated as periblem (12) and which give rise to the fundamental tissue system (primary cortex) of the twig.

A cross section of a young twig of *chir* (*Pinus longifolia*) at a somewhat greater distance from the growing point and prior to secondary thickening is shown diagrammatically in Figure XI, A. The epidermis (1) is well differentiated. Separating this from the vascular cylinder is an area of fundamental tissue, the primary cortex (2). The vascular stele is angular in outline and consists of segments of phloem and xylem (3) separated by fundamental tissue while the centre of the section is occupied by the pith (4).

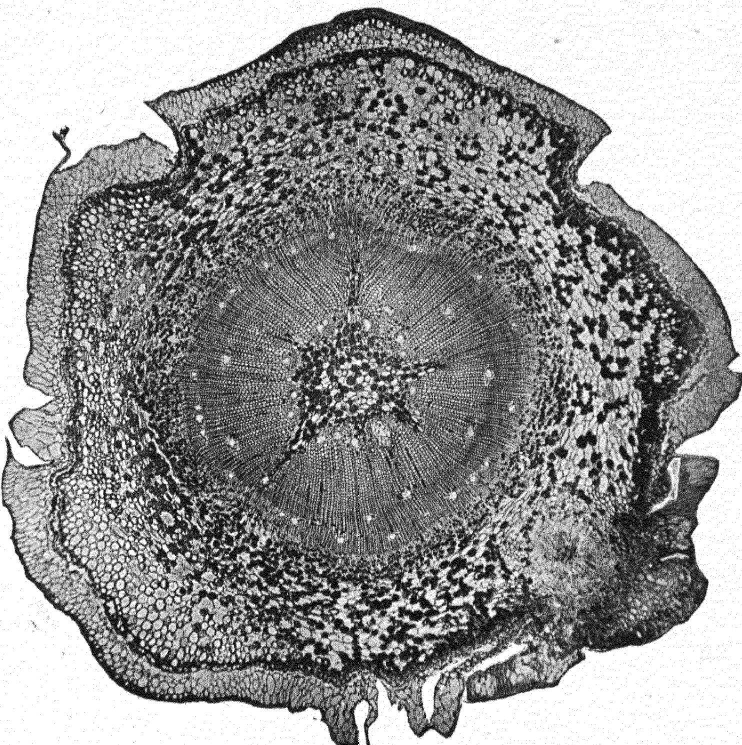
But Figure XI, A, does not represent the arrangement of the twig tissues at the end of the first season because no secondary growth is recorded and secondary growth is initiated the first year. Figure XI, B, indicates the conditions as found in a one-year twig of *chir* where secondary thickening has resulted. A lateral meristem (6) has arisen from the fundamental tissue originally separating the primary xylem and phloem which, through cell division, has produced secondary wood centripetally (5) and secondary phloem centrifugally (5^1) and these new tissues have been interpolated between the primary xylem (3) about the pith

and the primary phloem (3^1). As secondary growth proceeds the primary vascular tissues are pushed farther and farther apart and the primary phloem is finally sloughed off as bark through periderm formation (7).

Figure XII is a photomicrograph of a cross section of a one-year twig of *chir* pine. The orientation of the tissues is essentially that enumerated in the preceding paragraph. The centre of the field is occupied by the angular pith; the projections of pith into the surrounding xylem are due to leaf gaps, that is, to extensions of vascular tissue into the leaves. The primary xylem is immediately coterminous to the pith between the gaps. It is not sharply delimited from the secondary xylem which forms the bulk of the seasonal ring (more than 90 per cent.). Here and there in the wood are openings which at higher magnification prove to be resin canals. The cambium is situated on the outer face of the wood (annular in cross sections) and separates the secondary phloem from the xylem. The ring of phloem is comparatively narrow, less than one-fifth as wide as the wood, but like the wood, is indicated by the radial alignment of its cells. Without the phloem is a wide band of rounded cells extending to the epidermis which bounds the twig on its outer margin. These cells form the primary cortex and are a part of the fundamental tissue which originated in the growing point at the apex of the twig. Already provision has been made for bark formation since a cork layer, the periderm, has arisen several cells back in the primary cortex. In a two-year-old twig of *chir*, the epidermis and several outer layers of primary cortical cells will have disappeared, replaced by a layer of cork. The epidermis of twigs rarely continues to grow with the twig and is soon ruptured (generally the first or second year) and sloughed off but ere this takes place nature produces a new waterproofed layer of periderm beneath it. One further point requires elucidation in the photomicrograph. In the lower right hand portion of the primary cortex, a circular area of vascular tissue appears; this is a lateral branch which left the vascular stele below the plane of section on its way to the surface of the twig.

Year by year the cambium continues to form new xylem and phloem* and the tree stem thickens. But the bark of a tree is never as thick as the woody cylinder and for the

*The sieve tubes of the phloem function for one year only; a new layer of phloem is produced with each annual layer of wood.



Photomicrograph by H. P. Brown.

Figure XII —Photomicrograph of a cross section of a *chir* twig (*Pinus longifolia*) at the end of the first season. See figure XIB.

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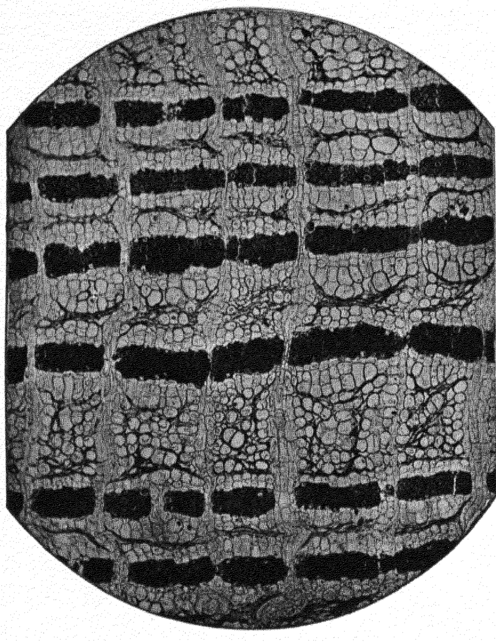

Photomicrograph by H. P. Brown.

Figure XIII.—Photomicrograph of a cross section of the older phloem of teak (*Tectona grandis*). The delicate tissue between the dark bands of bast fibres consists of thin walled sieve tubes, companion cells, and phloem parenchyma. The sieve tubes have ceased to function and have collapsed.

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following reasons. The walls of the cells which make up the wood are strongly lignified; they refuse to crush. But the walls of the sieve tubes which form a large part of the phloem remain unlignified. So long as the sieve tubes function, that is, during the first season, there is no collapse, but the second season finds them compressed and occupying but a fraction of the space of the preceding year (Figure XIII). Collapse of sieve tissues is undoubtedly brought about by contraction of the outer bark, in rare instances occasioned by cold or dry periods when cambial growth is not in progress.

While the cambium through cell division forms wood centripetally and phloem centrifugally, there is no reason to infer that like amounts of these two tissues are produced. The proportion of phloem to xylem varies in different tree speices and under different conditions of growth but is roughly one to five or six. The seasonal ring of phloem is approximately one-fifth as wide as the ring of xylem which was formed contemporaneously with it.

Finally, trees have developed a method of eliminating old useless phloem tissue through bark sloughing. In Figure XI, B, the first periderm is seen to be of corticular origin and to have cut off the epidermis and several layers of primary cortex cells. These are no longer a physiological part of the twig but will wither and turn brown, and eventually slough off, exposing the periderm beneath. The first periderm usually functions for some years and continues to keep up in growth with the enlarging twig; meanwhile the bark remains smooth and annually, increments of xylem and phloem are added to the stem. But sooner or later deep cork formation begins and is immediately evinced by a roughening of the bark. The new cork layers either take the form of short arcs which dip into the living underlying tissues (shell barked trees) or extend as rings completely around the stem (ring barked trees); the remaining primary cortex is the first to go, followed by the older phloems in the order of their formation. A "status quo" is eventually reached whereby bark sloughing keeps pace with phloem accumulation. Otherwise the old non-functional phloem layers would become a positive impediment in the further growth of the tree.

To sum up therefore, we may note that wood (xylem) accumulates in a tree because the walls of the cells which

compose it are lignified and refuse to crush under bark pressure. Phloem tissues are restricted in amount because (1) there is less phloem produced than xylem, (2) the walls of the sieve tubes of old phloem remain unlignified and crush, and (3) trees cast off old phloem tissues through periderm (cork) formation.

From the above it is possible to coin two definitions for bark. In the one case bark may be said to include all those tissues outside the true cambium. It follows that part of these would consist of living cells, that is, would still be a physiological part of the tree, the remainder dead desiccated cells without the last (inner) formed periderm. The other definition considers bark as comprising only those dead tissues without the last layer of periderm. It seems best to distinguish between inner living bark and outer dead bark, the two separated by the last periderm. The former may again be divided into (*a*) inner bark with functioning sieve tubes (the last phloem layer) and (*b*) inner bark which consists largely of phloem parenchyma cells (performing the storage function) and crushed non-functional sieve tubes.

Physiological Significance of Wood Formation.

Before proceeding to a discussion of wood anatomy, an understanding of the physiological significance of wood in trees is desirable because the plant organism is always attuned to the requirements of nature and the structural features of timber each have their *raison d'être*. In fact we have reason to believe that obsolete structures in nature do not long survive in point of geologic time and that persisting vestigial organs are comparatively rare in plants. On the other hand the tree is not to be considered a perfect organism, nor is it perfectly adjusted to its environment: it is sufficiently well adapted, however, to withstand the vicissitudes of present day conditions. Otherwise it would not have survived, for Nature is a stern disciplinarian and disobedience of her laws means elimination, sooner or later

The functions which wood performs in the life economy of the tree are (1) that of conduction of water and solutes, (2) the mechanical function, and (3) storage of reserve food, listed in the probable order of their appearance. Modern science teaches us that the higher vascular plants were evolved from simple non-vascular forms. As division of labour increased vascular tissue was developed as the most

logical means to move plant food rapidly from its place of manufacture to distant points where needed; in other words transportion facilities increased which in turn permitted increase in stature (volume). But concomitant with an increase in volume was a need for greater mechanical strength. The organism was no longer aquatic or semi-aquatic in habit nor could it rely on turgescence alone to maintain rigidity. It became terrestrial and was forced to lift its manufacturing organs (leaves) aloft and to compete with neighbouring individuals for that which is essential for the growth of all green plants, namely, light. To meet this further need and to obviate the development of a new type of tissue, another duty was delegated to the vascular system; it took over the mechanical function, that of insuring sufficient strength to stems, roots, and leaves.

The storage feature of vascular tissues undoubtedly developed much later. Vascular plants first attained ascendency during the Carboniferous period and were represented by dendroid forms allied to our ferns and fern allies (club-mosses, horse-tails, quill-worts) of to-day. The climate of this age is thought to have been warm and humid with no seasonal fluctuations. Growth was continuous throughout the year and the plants of that period required no devices for food storage; food was manufactured only as fast as required. But with further earth-cooling, a new set of conditions came into being. Seasonal fluctuations developed and but a portion of each year was favourable for plant growth,* at least in the majority of cases. Added to this was the development of seed plants as opposed to spore plants (ferns, etc.), which is but another response to an environment becoming more hostile, permitting of the tiding over of the organism during unfavourable cold and dry seasons and insuring greater dissemination. But dormancy during unfavourable periods in the year and seed formation required reserve food, food which had been accumulated during previous vegetative periods against a time of need. The leaves, where persistent, undoubtedly assumed the storage function to some extent (as in the conifers of to-day) but failed to provide sufficient space. To the fundamental system of twigs (primary cortex) the function of storage was in turn delegated but this was not ample to meet the need. The available cortical cells were fluxed

* Owing to fluctuations in temperature.

with food but the overflow must needs be deposited in the vascular core of the stem. In addition the rapid disappearance of the primary cortex in twigs precluded its use as a repository organ for any period of time and to the vascular system (phloem and wood) of the tree the storage function was assigned, again as an after thought on the part of nature occasioned by a change of the conditions under which plants were forced to live.

Of the three functions which wood performs in the life economy of the tree, undoubtedly that of conduction was originally responsible for the evolution of vascular tissue (including wood) but the increasing stature of plant organisms following its appearance required greater mechanical strength, and to the vascular system a subsidiary duty was delegated, that of insuring sufficient mechanical strength to the stem The storage function in all probability, was taken over long afterwards, as seasonal fluctuations in climate appeared and plants were forced to live under more rigorous conditions and to adapt themselves to a more hostile environment. In a study of wood anatomy it is well to keep these functions of wood in mind and to note the remarkable adaptations that Nature has made to insure the fulfilment of them.

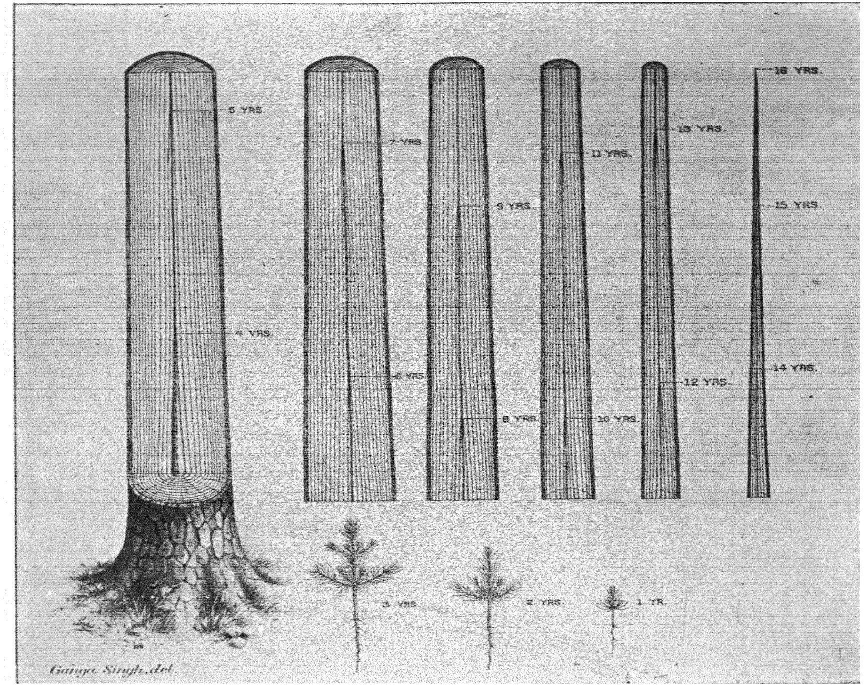

Figure XIV.—Schematic drawing illustrating the arrangement of season zones in *chir* pine (*Pinus longifolia*).

[To face page 41].

PART V.

The Gross Structural Features of Wood.

In approaching the subject of wood anatomy, the logical sequence is from the gross to the microscopic. It would seem desirable pedagogically to first acquaint the student with those features of wood which are decipherable with the naked eye or at low magnifications (10 × or less) Thus a basic knowledge is acquired, which is a boon to an understanding of the many details of microscopic structure which follow in the text. The following pages are based on this assumption as offering a convenient means of approach to the subject.

Seasonal Rings.

Growth rings are features of many woods and when present, are generally visible with the naked eye. The appellation of growth ring is a misnomer in a sense since such concentric zones appear as rings only in cross sections of the log. Figure XIV depicts diagrammatically the growth zones in a tree sixteen years of age. Tree-stems exhibit radial symmetry and the seasonal increments in cross sections of the bole take the form of concentric annular bands about the pith. Thirteen such bands are registered on the stump because it took the seedling four years to attain to stump height. The increase in height and thickness through the addition of further seasonal increments can be followed in the diagram. Each year's growth takes the form of a hollow cone or paraboloid and is inserted on that of the previous year. It follows that the number of annual rings dwindles in cross sections of the bole as the apex of the tree is approached and furthermore, that a given ring is wider in diameter at the top than near the bottom of the stem*; otherwise the symmetry of the organism would be upset.

Annual rings are evidence of growth rhythm in trees; the cambium is very active at one season and dormant or sluggish at another. Cold (winter) or dry periods inhibit or prevent growth since temperature and moisture are the

* Many trees exhibit buttressing at the base at the root-crown. The seasonal rings in such cases may be very wide but dwindle rapidly in size above, only to increase gradually in thickness again as the crown is approached.

most potent factors in the activation of meristematic tissue. It was thought at one time that rhythmatic growth was more or less independent of outside factors; that cell division began at the same time each season in trees of a given locality because trees had become creatures of habit. Modern research, however, has eliminated the mysterious in seasonal growth, has reduced it to physiological laws which rest on a sound basis. Trees grow only when climatic conditions (temperature and moisture) permit. Water plays a very important role in the process and growth proceeds most rapidly during the hours of darkness, a condi tion to be explained in that transpiration (voiding of water) is less rapid from the leaves at night while the roots continue to pump water into the stem. The meristematic tissues (growing points) become fluxed with moisture (turgid) and growth is hastened thereby.*

Not only are seasonal rings an evidence of varying growth intensity in trees but also of a shifting of the paramount function which the newly forming wood performs in the tree as the season advances. The early (spring wood) part of the ring is more open in structure than the dense outer (late or summerwood) portion. In fact the greater the discrepancy between these two zones in the ring, the sharper the annual layers are delimited in the wood. At the beginning of the season when the buds are unfolding and growth in length is progressing rapidly, there is a demand for the rapid movement of water and foods in solution (reserve food that has again been rendered soluble) to the growing apices. The forming wood cells in the new ring reflect this need; they remain comparatively thin walled or modified in various ways to insure the rapid movement of moisture; the mechanical function is subjugated to that of conduction in so far as the element of safety permits of it. But the majority of woody plants exhibit definite length-growth and the latter ceases some days or weeks before growth in thickness.† As the season advances and elongation is retarded or stops altogether, demand for the rapid movement of soluble food dwindles. At the same time thickening-growth becomes more sluggish and greater attention is devoted by the organism to the mechanical func-

* For methods of measuring seasonal growth in trees, see the Indian Forester, 49 : 293-301, 1923.

† In the majority of the woody plants of the "temperate" zones elongation in twigs ceases by mid-summer and the remainder of the growing period is devoted to a hardening of the newly formed tissues and to growth in thickness.

understanding of the significance of heartwood formation is requisite to the study of wood anatomy as its presence or absence has an important bearing on the utilisation of timber.

The most striking features which characterize sap and heartwood are those of colour, weight, and durability; heartwood is generally darker, heavier and more durable than sapwood but the colour character must be used with reservation. There are trees in which there is no true heartwood, at least in so far as colour is concerned; numbered among these are spruce, fir and *papri* (*Holoptelea integrifolia*). But this does not signify that true physiological heartwood is absent since real heartwood may be present in every sense but that of colour. The deeper colour and greater durability of heartwood are traceable to the physiology of its formation. As the term implies, sapwood is concerned with the movement of sap (dilute aqueous solutions of mineral and organic food) up the stem; heartwood performs purely the mechanical function in the core of the tree. Sapwood possesses living cells which make up roughly from three to forty per cent of its bulk as compared to the remaining dead tracheal elements. The cells of the heartwood are all dead and play no part in sap movement.*

As sapwood passes over into heartwood and its parenchyma (living) cells die, a peculiar physical and chemical change takes place†. Organic compounds are formed which may or may not be by-products of cell necrosis but which become infiltrated into cell walls and may even accumulate, generally as amorphous deposits, in cell cavities. The range of such products is very great, consisting of tannins, dye-stuffs of various sorts‡, the salts of organic acids, etc., and the heartwood of trees has become a source of

* The reason for the rise of sap in trees has been one of the conundrums of botany Some plant physiologists have attempted to account for it on purely physical grounds with but partial success More recently the vitalistic theory has been revived by Bose who ascribes the rise of sap to the pumping action of living cells coterminous to the tracheal tracts

† The process of lignification in trees is often confused with that of heartwood formation but is in no wise concerned with it. As pointed out on page 26, lignification of woody cells follows rapidly their formation in the lateral cambium. The last growth ring at the end of the growing season is as lignified as it will ever become and no further changes of this character ensue as it passes over eventually into heartwood. The corollary follows that sapwood, being as lignified as heartwood, is fully as strong under identical conditions of moisture

‡ Of the dyewoods of commerce probably hæmatoxylin (*Hæmatoxylon campechianum*) and fustic (*Chlorophora tinctoria*) are the best known. The dyestuff may be infiltrated into the wood "in situ" or take the form of a chromogen, requiring further chemical treatment ere its dye-principal becomes apparent.

many products useful to man. The infiltration causes a darkening of the tissue* concerned and the durability of the wood is often greatly enhanced. In the exploitation of many timbers, depreciation in sapwood due to fungal or insect attack is so rapid that it is removed prior to shipment of the logs to points of consumption.

The rapidity and progress of heartwood formation varies greatly in different trees. In some the sapwood is very narrow and consists of but two or three rings at the most. The other extreme is found in forms with wide sapwood consisting of sixty or more seasonal layers. Seasonal zones do not of necessity pass over into heartwood as entities; a given ring may have been incorporated in the heartwood on one side of a tree and still be a functional part of the sapwood elsewhere in the stem. In the majority of trees duramen formation is apparently a gradual process which progresses at a steady pace but there are woods (*Garuga pinnata*) which exhibit zonation of the heartwood, a condition indicative of fluctuations in the rate of heartwood formation; such zones bear no relation to seasonal thickening.

There remains but to point out the relation which heartwood bears to the moisture content of the tree and here a peculiar division arises. In the majority of coniferous trees the sapwood is much richer in water than the heartwood and may contain moisture up to two hundred per cent. of its dry weight. In hard woods (dicotyledons) to the contrary, the moisture is generally evenly distributed through heart- and sapwood. Such green woods may be naturally quite dry or seem very wet as they come from the living tree.

Wood Rays.

Wood rays or medullary rays as they are erroneously called are gross features of many woods.† Their shape and alignment in the tree are depicted in Figure XV. On the cross section of the log they appear as lines or streaks of tissue which extend from the bark through the cambium for varying distances into the wood, the first formed or

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* The colour range of heartwoods is too well known to deserve description here

† They are always present but are sometimes too fine to be visible with the naked eye.

primary to the pith.* The function of wood rays is obvious if one considers the movement of sap and of elaborated food in the tree. The former rises in the sapwood while the food elaborated in the leaves moves downward in the inner bark. The wood rays take this up in driblets and pass it radially to the growing layer (cambium) where needed or, if growth is proceeding sluggishly, quantities of food pass through the cambium and are stored in the rays of the wood, only to be removed during the following period of elongation and dumped into the ascending sap stream. Wood rays are organs for radial conduction and for storage in the tree.

Figure XV depicts the three planes of section in which it is customary to study wood, namely, the transverse or cross, the radial, and the tangential; the two last are longitudinal planes (vertical in the standing tree), the one parallel to wood rays and at right angles to seasonal rings, the other tangent to seasonal rings and at right angles to the wood rays. In the tangential section the radial lines of the transverse cut which represent wood rays give place to short vertical lines which are scattered over the field without definite arrangement and which indicate the height and thickness of rays, the latter themselves being cut transversely.

The above arrangement characterizes the majority of Indian woods but certain timbers are peculiar in that their rays appear in echelon (in stories like windows in a building) and give rise to ripple marks on a tangential section. Storied rays may be constant features of all the Indian species of a genus (*Dalbergia*, *Pterocarpus*) or restricted to certain species as *Bombax insigne* (as opposed to *B. malabaricum*.) They offer a diagnostic feature of first importance in the identification of wood.

On the radial face of the block the lateral surface view of the ray is exposed; it appears as a band of tissue extending toward or in the case of the primary rays, reaching to the pith.† Wood rays are continued out into the bark as far as the old phloem extends, the primary reaching the greatest distance.

* The arrangement of wood elements has sometimes been compared to the warp and woof of textiles The majority of the wood cells are arranged with their long axes longitudinal in the log, that is, in the direction of the sap stream, and form the warp in the analogy above, but coursing between these in a radial direction are aggregates of cells which are elongated in the radial direction, the wood rays or woof.

† As a tree increases in girth, secondary rays originate in response to necessity in the cambium and are interpolated between the primary rays.

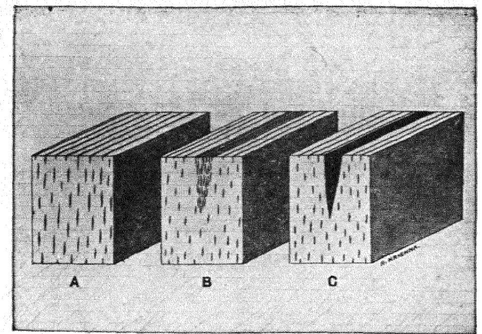

Figure XVI.—Schematic drawing illustrating the various ways in which wood rays are arranged in dicotyledonous woods. A, Diffused rays; B, Aggregate ray accompanied in addition by scattered rays; C, Compound ray accompanied in addition by scattered rays.

[To face page 47].

In coniferous and many dicotyledonous woods, the radial bands are too fine to be seen clearly at low magnifications but they are always present in tree stems produced in the normal way. Large rays are constant features of other dicotyledonous trees such as oak, sycamore, *Carallia* species, etc., and appear either as radial lines in cross sections or forming pronounced ray-flecks on the radial face of lumber. It is customary to quarter saw (Figure XVIII, 9) such woods to enhance the figure, a " silver grain " resulting.

Wood rays have been classified in various ways according to their respective anatomical characters, or phylogenetic origin. Classifications of the first sort have little bearing in a discussion of gross features but mention should be made of the last since the several phylogenetic ray-types are found in modern woods and are sometimes used in keys for wood identification.

Where the rays are of equal width (as seen in cross sections of the tissue) and evenly spaced, they are said to be of the diffuse type (Figure XVI, A). This is the condition in all coniferous and in the majority of dicotyledonous trees (*Lagerstrœmias*, *Terminalias*, etc.). But a few woods show a tendency toward the massing of numbers of such simple rays into larger units containing inclusions of tracheal tissue, such aggregations then being designated as aggregate rays (Figure XVI, B). Structures of this type appear at intervals in the tissue, separated by diffuse rays and are features of the wood of *Alnus nitida* and certain oaks such as *Quercus Ilex*. Where aggregation is carried to the final stage, the tracheal inclusions are eliminated entirely and compound rays (Figure XVI, C) are produced that are many times larger than the diffuse simple rays which are scattered between them. This is the condition in the xylem of the majority of the oaks which are featured by two sorts of radial bands, the larger broad type that are visible with the naked eye and give rise to the silvery grain of quarter-sawn stock, and small rays (many) between them which are only discernible with a lens.

For reasons which cannot be described in an elementary treatise of this sort the aggregate ray is considered to have been the primitive type and to have given rise on the one hand, through spreading fanwise, to the diffuse condition, and through the elimination of tracheal inclusions on the other, to the compound type. Where compound or aggre-

gate rays are present, they present a diagnostic feature of some importance.

Vessels.

Dicotyledonous woods in contrast to coniferous are characterized by the presence of vessels* which in cross sections are designated as pores; hence the origin of the term non-porous and porous as applied respectively to coniferous and dicotyledonous timbers (see Plates I to XII inclusive). A vessel or duct is to be considered as a composite element which arises through cell fusion. A longitudinal (vertical in the tree) row of cells increases in diameter and the end walls become perforated either completely or in a latticed manner. An articulated tube results with joints at intervals (see Plates XII and XIV), the latter indicating the terminations of the cells that entered into its formation. An analogous condition would arise were a number of barrels to be stacked one upon another and the heads knocked out. Vessels or ducts are not continuous in the tree from roots to leaves but extend for varying distances (several feet) and are eventually replaced by neighbouring elements of like nature with which they overlap.

The size and arrangement of vessels is very variable and such departures offer a valuable aid in the determination of species. In *semul* (Plate XVI) and the various species of *Artocarpus* they are very wide and the orifice or pore can be plainly distinguished with the naked eye on smooth cross sections. Such woods are coarse textured and the faces of boards are marked by streaks or lines which indicate the longitudinal course of the ducts through the wood. The other extreme is found in boxwood (*Buxus sempervirens*), the Himalayan horse-chesnut (*Aesculus indica*), and the various *Gardenias*, substitutes for boxwood, where, even with a hand lens, they appear as white dots which only assume the form of pores at higher magnifications. Two general types of vessel arrangement are distinguished which feature ring and diffuse porous woods respectively. The former possess pronounced growth rings, in which the vessels of the spring wood are conspicuously larger or more numerous than those of the summer wood. This type is comparatively rare among Indian woods but

*The terms duct and trachea are synonymous with vessel.

is characteristic of teak, *toon* (*Cedrela Toona*) and the various deciduous oaks. As pointed out on page 42, it is indicative of a change during the growing period of the paramount function which the new wood is called upon to perform in the life economy of the tree; the large pores develop quickly at the start of the season and facilitate the rapid movement of soluble food to the growing apices of twigs and roots while the mechanical function becomes of foremost importance during the formation of the outer part of the ring and the vessels are greatly restricted in diameter as a result.

In diffuse porous woods the ducts vary little in size and are scattered through the seasonal ring individually or in small groups. There is little or no evidence that the tree required greater amounts of food and moisture at the inception of the active season and growth appears to have progressed steadily and evenly throughout the whole period. In fact one may well infer that thickening in such trees is extremely conservative and in addition there is some evidence to indicate that seasonal growth proceeds for a longer period and that growth intensity never mounts as high during the formation of the spring wood as in trees of the ring-porous type.

The majority of Indian dicotyledonous timbers are diffuse porous and undoubtedly result from an extended growing season contingent on temperatures which permit of growth over a long period. Woods of this sort, however, are not confined to tropical or subtropical regions, as the birch, beech, and maple of the north temperature zone are familiar examples. Undoubtedly other edaphic adaptations of individual tree-species are responsible in some cases at least for the ring and diffuse porous types since these appear in extra-tropical regions; tropical woods in the main incline toward homogeneous structure.

Various sub-types of vessel arrangement are to be distinguished, which occur irrespective of the gross grouping described in the preceding paragraph. For example a wood may be strictly diffuse porous and in addition present modifications as follows. The pores may be in short radial rows of from two to ten or more (Plate V), or in interrupted or continuous tangential lines, or in nests. The *Calophyllums* and certain other woods of the *Guttiferæ* are characterized by radially oblique, flame-like groups of ducts and the same

holds true for *Castanopsis* in the *Fagaceæ*. The summer wood vessels of ring porous woods in no way conform in grouping to those of the spring wood but may be variously arranged in wavy tangential lines that are more or less continuous (*Ulmus*) or interrupted (*Morus*). Such features are constant and may be used to advantage in the identification of these timbers.

It was pointed out on page 44, that heartwood as a rule is darker, heavier and more durable than sapwood; vessels when present are of significance in the changes which take place in this process since they serve as repositories for infiltration products of all sorts. For example the vessels of Leguminaceous and Meliaceous woods often contain gums of various kinds which may occlude the vessels completely or, as is usually the case, form irregular masses or plugs at intervals which span the vessel cavity at its constrictions. Such plugs are features of the wood of *Dysoxylum* and of satinwood (*Chloroxylon Swietenia*). White amorphous deposits fill occasional vessels here and there in certain woods and are not an uncommon feature. Such deposits may occur quite independently of gums (*Artocarpus* species) or accompany them as well (*Acacia Catechu*). The chemistry of infiltration products is a study in itself and lies beyond the realm of the anatomist. Many compounds have been identified to date, as for example the silicon of teak, but there is still ample opportunity to enlarge the field of minor forest products. Such deposits are of importance diagnostically, especially in those woods in which they appear as constant features.

Tyloses.

Tyloses often accompany vessels and are morphological features of many woods (*Lagerstrœmias*, *Shoreas*, etc.). At low magnifications they present a foam-like or chaffy appearance in the vessels on the faces of boards* and the pores may in extreme cases become entirely occluded with them (Plates VII and X). The origin and formation of tyloses will be dealt with in detail when the microscopical features of wood are discussed. While they are occasionally found in sapwood and in elements other than vessels, by far the greatest number are produced in the vessels as the sapwood passes over into heartwood.

* Tyloses are sometimes indistinct as viewed with a lens

Tyloses are indicative of durability in wood because they impede the movement of air and moisture. Fungi and insects are the chief enemies of timber and the former require oxygen, moisture, and suitable temperatures for growth; if these are restricted below the optimum, fungal growth is thereby inhibited. Many of the woods which prove to be durable in contact with the soil and make suitable railway sleepers are featured by abundant tyloses and such woods treat with preservatives with difficulty since infilteration is restricted or prevented entirely because of the closed pores.

Resin Cavities.

Certain woods are characterized by the presence of resin cavities which take the form of canals or openings of irregular contour that contain resin in various stages of hardening. (See Plates I, II, VII and VIII). The tubular types are sometimes designated as resin ducts but this term is misleading since they bear no relation to true ducts (vessels) in their manner of origin. Resin cavities are intercellular spaces which arise through the pulling apart of cells (schizogeneously) or through liquefaction of cell-wall substance (lysigeneously), possibly in both ways in some instances.

The irregular type of resin cavity is found exceptionally in many woods which are included in a wide range of genera. They are not infrequent in the *Cordias* and occur occasionally in such woods as *Anogeissus latifolia*, *Cedrela Toona*, etc. Such cavities arise through disintegration of cell-wall substance into gummy material and are undoubtedly due to the stress of unusual conditions such as mechanical injury to the cambium or infection with bacteria and fungi.

Tubular resin cavities or canals are of post-cambial development and may be of normal or traumatic occurrence. The former are constant features of the secondary wood of certain coniferous (*Pinus*, Plate I; *Picea*, Plate II) and dicotyledenous (*Shorea*, Plate VII) genera, and may course both longitudinally and transversely in the wood or be restricted to but one of these directions. Longitudinal canals extend irrespective of the wood rays though in intimate connection with them but the transverse types are always found as ray inclusions.

Pine and spruce wood have both vertical and horizontal canals. The faces of pine boards are usually marked with darkish streaks which extend for long distances in the wood and owe their origin to the resin in the canals at the surface which tends to catch and hold dust (following the conversion of the wood into lumber) and to " take " varnish. The resin canals of spruce in comparison are far less conspicuous than those of pine and are usually overlooked unless the wood is examined carefully with a lens. Even at magnifications of 10 x, the cavities of the canals are not discernible ordinarily and white flecks in the transverse sections are the only proof of their presence.

The resin cavities of dipterocarps (*Dipterocarpus*, Plate VIII; *Shorea*, Plate VII; *Hopea*, etc.), in comparison are generally restricted to the longitudinal type* and may be very abundant and diffused through the wood as inclusions in parenchyma (*Dipterocarpus obtusifolius*, Plate VIII), or restricted to rows which extend tangentially for long distances in the tissue and appear at frequent (*Shorea robusta*, Plate VII) or infrequent (*Hopea odorata*) intervals.

Radially aligned canals alone feature the woods of the genera *Odina*, *Buchanania*, *Gluta* (Plate X), and *Melanorrhoea* of the *Anacardiaceae*, of *Boswellia* of the *Burseraceae*, and of *Heptapleurum* of the *Araliaceae*. As a rule they are less conspicuous than the longitudinal cavities and are generally overlooked in the examination of the wood at low magnifications.

Traumatic canals as the term implies are a wound reaction and are not uncommon features of certain coniferous woods in which normal resin cavities are wanting. When present, they are usually aligned in tangential rows of a dozen or more which extend along the outer face of a seasonal ring though they are not of necessity restricted to that position. Normal canals are wanting in the wood of deodar but both vertical and horizontal traumatic resin cavities are of frequent occurrence and offer a diagnostic feature of some importance (Plate III). The traumatic canals of coniferous wood can be distinguished from those of the normal type owing to their sporadic appearance in tangential rows in widely separated rings. There is reason to infer that the concentrically aligned canals of such Dipterocarp woods as *Hopea parviflora*, *Hopea Wightiana*,

* Strictly so in the Indian species.

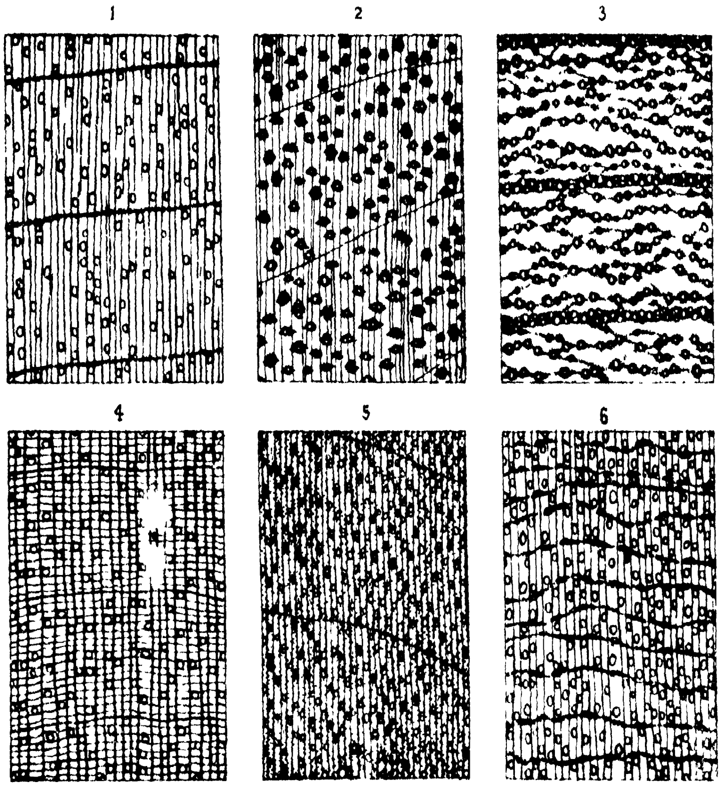

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Figure XVII.—Schematic drawing illustrating the various types of arrangement of longitudinal wood parenchyma. 1, Terminal on the outer face of the seasonal ring; 2, Paratracheal; 3, Paratracheal zonate; 4, Metatracheal zonate forming a reticulum with the wood rays; 5, Metatracheal diffused; 6, Tangential bands which extend irrespective of pores

[*To face page 58.*

etc., belong to the traumatic category but this requires further research for elucidation.

The relation of resin cavities to minor forest products is too well known to deserve more than mention here The turpentines and pine tar of commerce are products of such structures in *Pinus* and the industry promises to be of no small significance in India, especially so with the wane in American supplies. *Boswellia serrata* is the source of a gum oleo-resin which has its inception in horizontal resin-canals and this Indian industry has great promise in the Central Provinces and in the Bombay Presidency.

Longitudinal Wood Parenchyma.

Longitudinal parenchyma cells* as individuals are usually too minute to be clearly visible at low magnifications but when they are very abundant and variously grouped in lines or banked about pores, they present features of taxonomic value, especially in the determination of dicotyledonous timbers.

The several types of parenchyma grouping are depicted in Figure XVII, though it must be understood that all gradations occur between them and various combinations feature specific woods. Three general types are discernible, the terminal (at the end of the annual ring), the metatracheal (between the vessels and irrespective of them), and the paratracheal (about the vessels). The first is found in many of the Magnoliaceous woods such as *Michelia* (Figure XVII, 1), *Talauma*, and *Magnolia*, in some of the *Acacias*, in *Chickrassia* and *Chloroxylon* of the *Meliaceae*, and elsewhere. The parenchyma is prominent on the outer face of the summer wood and forms a more or less definite line delimiting the growth zone.

The paratracheal arrangement is a conspicuous feature of most of the Leguminaceous woods, of many of the timbers of the *Combretaceæ*, the *Anacardiaceæ* and other plant families. Here the parenchyma shows a strong tendency toward grouping about the pores and the latter appear thick-walled, haloed, or as eyelets (Figure XVII, 2) which are set in masses of light coloured (as contrasted to the darker masses of fibres) tissue. Often these areas of paratracheal parenchyma are elongated tangentially, and may

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* As distinguished from those included in wood rays.

coalesce with those from other pores to form more (*Lagerstrœmia Flos-Reginœ*) (Figure XVII, 3) or less (*Terminalia tomentosa*) continuous bands of parenchyma which include the pores (paratrachael-zonate). It follows that many modifications of this type are possible and are present in different woods or in the wood of one and the same species that has grown under different conditions.

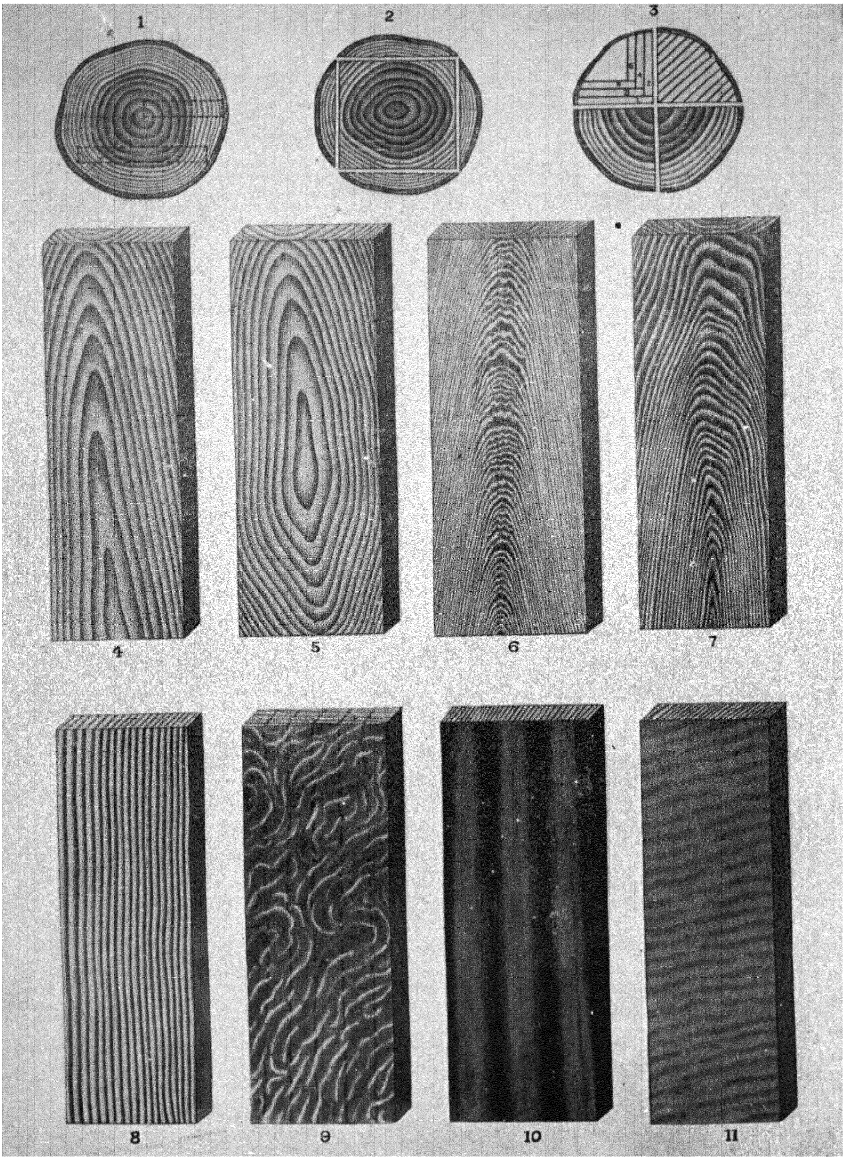
In the metatracheal type the parenchymatous cells are found between the vessels, embedded in the fibrous tissue, and may be aligned in conspicuous bands which extend tangentially and run irrespective of the pores (*Mesua*, *Kayea*, *Calophyllum*) (Figure XVII, 6) or form fine tangential lines or punctate fields. *Juglans regia*, the various *Diospyros* species, and woods of the *Anonaceœ* (Figure XVII, 4) and *Sapotaceœ* illustrate the metatracheal-zonate alignment in which the lines of parenchyma connect wood rays and build a close-meshed reticulum that is of value in identification. The punctuate arrangement (metatracheal-diffused) is a feature of many Rubiaceous woods (*Adina*, *Hymenodictyon*, *Stephegyne*) and in addition of *Bombax*, *Betula*, *Sterculia*, *Pterospermum* (Figure XVII, 5), *Heritiera*, etc. A " salt and pepper " effect is produced since the scattered parenchyma cells appear as dots scattered through the field of fibrous tissue between the rays and pores.

The distribution of parenchyma in wood, in spite of the fluctuation in its arrangement, is of importance diagnostically and the wood technologist must number it among the features worthy of careful consideration.

Grain and Texture.

Much confusion has arisen owing to a loose usage of the terms " grain " and " texture " but this may be largely avoided if they are considered as having definite limits of application. Grain has to do with the alignment of wood elements, that is, the manner and direction in which they are arranged; texture is concerned with the size of wood elements. Both require adjective modifiers to convey specific meaning and many have been applied, either correctly or otherwise.

Straight-grained timbers have their longitudinal cells aligned vertically or nearly so in the tree and such woods split readily because there is little inter-locking of the tissues. Strictly, straight-grained trees are comparatively



Canga Singh, del.

Figure XVIII.—Diagrammatic drawings to illustrate the manner in which logs are sawn and the figures which result. 1, End of log showing the relation of flat-sawn and quarter-sawn boards to the log ; 2, End of log showing the usual way of flat sawing lumber ; 3, End of log showing two ways of quarter sawing lumber ; 4, Face of a flat-sawn board from a log of decided taper ; 5, Face of a flat-sawn board from a log of little or no taper ; 6, Face of a board showing "partridge" mottling ; 7, Face of a board showing "tortoiseshell" mottling ; 8, Face of a coniferous board showing "edge" grain ; 9, Face of an oak board showing "silver" grain ; 10, Face of a sal board showing "ribbon" (interlocked) grain ; 11, Face of a board showing "curly" grain.

[To face page 55]

rare and slight spiraling is the rule but this is generally overlooked unless it is pronounced.

All degrees of spiraling are found which are features of certain species or develop on occasion in trees which are normally straight-grained. In such instances, spiral alignment undoubtedly owes its origin to such factors as type of site, direction of prevailing wind, crown development, and available light, but the subject is not well understood at the present time though much has been written upon it. The stands of *chir* pine in parts of the Western Himalayan region are well nigh useless for timber because of the pronounced spiraling which they exhibit and the question has arisen whether this is an inheritable characteristic or arises anew in each tree because of the environmental conditions in force. The former might account for its prevalence in *chir* over wide areas since the rotation of this species may be fairly estimated at eighty years and spiraled trees have been left repeatedly near villages to re-seed the areas denuded through the felling of straight-grained stock.

Spiraling in trees is usually from right to left and results from an oblique alignment of the longitudinal elements of wood, not in a twist or bending of individual cells.* But left to right spiraling is not uncommon and may develop in a mature tree which exhibited right to left alignment at an earlier period, and particularly is this true in parts of the crown. Such reversal in tolerant species (spruce) may be traceable to light conditions since suppressed individuals are known to reverse the direction following a release cutting or recovery from suppression.

A peculiar condition has arisen in many tropical trees in that a spiral-reversal takes place every three or four years and wood is produced with interlocked grain (*Shorea robusta*, *Pterocarpus Marsupium*, *Calophyllum tomentosum*, etc.). These timbers are extremely difficult to split and when quarter-sawn, produce a beautiful ribbon-grain, the longitudinal bands which reflect the light differently being traceable to a reversal in the spiral at intervals along the radius of the log (Figure XVIII, 10). Such woods are extremely tough and are to be recommended for use where sudden strains are applied along the grain, as in gun carriages and wheel spokes.

* It would be impossible to determine the presence of spiraling in wood by an examination of its individual fibres.

Some timbers exhibit a rippling or waviness of fibre alignment which generally develops in the radial plane. Where the undulations are shallow and broad, a wavy figure is produced in quarter-sawn stock and broad bands extend across the grain* which reflect the light differently Curly figure owes its origin to abrupt, deep fibre undulations and is prized for violin backs (maple) and cabinet work. Curly and wavy grain (Figure XVIII, 11) in contrast to the interlocked condition (10) are comparatively rare among Indian woods (*Chickrassia tabularis*, *Xylia dolabriformis*, *Anogeissus latifolia*, *Terminalia Chebula*, *Lagerstrœmia Flos-Reginæ*. *Dillenia pentagyna*, etc.) but are not unusual in many of the trees of the north temperate zone (*Fraxinus*, *Sequoia*, *Acer*, *Juglans*).

Silver grain may be produced by quarter-sawing woods which possess large conspicuous rays. The ray tissue is dense and radially aligned in the tree and when seen in mass in lateral view, is lustrous and reflects the light differently than the longitudinal elements; in other words it forms a ray-fleck and these, taken together, are responsible for the figure of quarter-sawn boards of *Quercus* (Figure XVIII, 9), *Platanus*, *Carallia*, *Rhizophora*, *Helicia*, etc.

Burl or burrs and bird's-eye figures are due to variation from the normal fibre alignment which results from abnormal (adventitious) buds. Bird's-eye maple is known the world over and derives its name from included buds which, as seen in " flat-sawn " boards, recall birds' eyes. Many adventitious buds form in the cambium underlying the bark which fail to develop further but become imbedded in the wood. Fibre alignment is altered near such buds and an eye is produced, the pupil being the bud-axis. Burl is undoubtedly of pathologic origin and may result from mechanical injury or infection by fungi or bacteria. A large wart-like excrescence is produced on the trunk or on a large limb which when sectioned produces a beautiful and variable burl figure. Walnut (*Juglans regia*) and ash (*Fraxinus*) burls are highly prized in the trade.

Fibre alignment is also altered where large limbs or branches enter the parent stem and cabinet makers take advantage of this to obtain the beautiful " crotch " figures

* Such streaks bear no relation to wood rays.

which are usually put on the market in the form of veneer. Crotch-mahogany is familiar to dealers in cabinet woods but it follows that crotch figures can be produced from other trees as well by sawing in a similar manner.

Many adjective modifiers have been applied to " grain " which are misleading. A wood is often called coarse- or uneven-grained when it is matter of texture, that is, of the size of wood elements rather than their alignment. It is best to restrict grain to fibre alignment and in the use of adjective modifiers to decide first whether the feature in question is that of " grain " or of " texture."

Texture has to do with the size and thickness of the cells which in the aggregate constitute wood. Where the latter is of simple structure with uniform small wood rays and longitudinal cells largely of one sort (coniferous wood), it is comparatively easy to establish an index of texture-coarseness or fineness. For example the best criterion in pine wood is the average tangential diameter of the longitudinal fibrous cells (tracheids) and the various species of pine vary widely in this respect, but considerable uniformity is found in one and the same species.* Blue pine (*Pinus excelsa*) is of relatively fine texture, then follow *chir* (*Pinus longifolia*), Khasi pine (*Pinus Khasya*) and Tenasserim pine (*Pinus Merkusii*) in the order named.† In fact the texture of coniferous wood is of no mean value in the determination of species which are otherwise very similar in their anatomical structure

It is much more difficult to give an index of texture for dicotyledonous woods owing to their more complex anatomical structure. Coarse texture may ensue in diffuse porous woods from large wood rays alone (*Carallia integerrima*) or from large rays and large longitudinal elements as well (vessels, parenchyma, and fibres) as in *Bombax malabaricum*. Many of the tea-box woods such as *Endospermum chinense*, *Tetrameles nudiflora*, and *Artocarpus Chaplasha* have rays of moderate size but are coarse textured because of large pores, large longitudinal parenchyma cells, and fibres with thin walls and wide lumina. Such woods are soft and possess little strength but are readily cut into veneer for

* It requires a number of years (10-50) before the cambial initials of a tree attain their maximum size. After that there is very little fluctuation in the average tangential diameter of the fibrous cells in coniferous woods.

† See table of anatomical data of Indian coniferous woods, column 6, facing page 83.

plywood. Another type of variation is presented by certain Euphorbiaceous and Urticaceous woods in which the wood rays and vessels are of moderate size but the parenchyma cells and fibres are broad and wide lumened. *Bischofia javanica* must be classed as coarse textured though its vessels are not conspicuous and the same may be said of *Phyllanthus Emblica* and *Bœhmeria rugulosa*. Any element or composite element (rays and vessels) of dicotyledonous wood, if of unusual size or abundance, may coarsen the texture of wood materially.

Woods with pronounced seasonal zones more especially those in which the summerwood is conspicuous and the transition between spring and summerwood abrupt, may be fine or coarse textured but it follows that they must always be uneven textured (Plate I). The wide lumened, thin-walled cells of the springwood portion of a seasonal ring of a coniferous wood give place to tabular, thick walled cells in the summerwood. A difference in texture develops which is the more accentuated the wider the extremes of structure. The late-wood vessels of a ring porous wood are usually much reduced in size and uneven texture is the result. The oaks, teak, and *toon* (*Cedrela Toona*) illustrate this condition. Furthermore, when the ring-width is restricted in such trees, coarser wood of a poorer quality results since this reduction is always made at the expense of the denser summerwood. Second growth hickory from young vigorous trees is preferred over that from old over-mature individuals because it is much stronger owing to its wider growth rings, and the same would hold true for teak and *toon*.

Figure in Wood.

Figure in wood results from various causes such as seasonal rings, conspicuous wood rays, bands of parenchyma or undulation or spiraling of longitudinal elements. It follows that it may be greatly enhanced by the plane of section in which the wood is exposed and it is customary to go to much trouble to saw ornamental timbers in a certain manner. This phase of wood utilisation deserves further study.

Figure XVIII, 1, 2, 3 indicates two ways in which logs are sawn into boards and some of the figures which result are depicted below. When a log is slabbed as in 2 and then

converted into lumber (flat or bastard sawn), the majority of the planks will show the layers of seasonal thickening in tangential (surface) view. Number 4 shows the face of a pine board from a log of decided taper, that is, from a small rapidly growing tree or near the crown or buttressed base of a large tree. That of number 5 is from a large log. The overlapping zones are due in this case to spring and summer-wood but an effect approaching this might be produced by flat sawing such timbers as *Chickrassia tabularis*, *Calophyllum tomentosum and Melanorrhœa usitata* because of the tangential bands of parenchyma present in these woods. The mottlings of numbers 6 and 7 are designated in the trade respectively as "partridge" and "tortoise-shell" figure.

Logs may be quarter sawn in either of the two ways shown in Figure XVIII, 3. Both are wasteful methods and are not followed unless the durability or beauty of the wood is sufficiently increased to warrant a higher selling price. Coniferous wood (number 7) is sometimes quartered when it is to be used as flooring. The "edge grain" board which results wears much more evenly under foot than "flat-sawn" coniferous stock. Oak and other large rayed timbers are quartered for the silver grain (9) (see page 55). Woods with interlocked grain (*Calophyllums*, *Shoreas*, etc.) show ribbon figure (10) when quarter sawn, and curly figure (11) is best brought out in this way because the fibre undulations are generally in the radial plane.

It follows that the figure of veneer wood is variable depending on how the cut is made. Rotary cut veneer will exhibit the figures of flat sawn timber. Sliced or sawn veneer is usually cut along the radii of the log and the figures of quarter sawn boards are produced.

Knots.

Knots are of no diagnostic value in the identification of wood but are numbered among its gross features and deserve mention here. They result from branch bases which become included in the trunkwood of the tree and are always present though variable in number depending on (*a*) the kind of tree, (*b*) the age of the tree, (*c*) the conditions in force (light, etc.) when the tree grew, and finally (*d*) the place in the tree from which the wood was taken.

In a log from the base of a mature tree there may be no knots whatsoever in the outer portion of the wood but a number appear as the centre is approached. This is explained in that the crown of the tree was at that point at one time but crown development passed on, not through a lifting of the crown itself but owing to the elimination of branches at its base and the formation of new branches at the top (acropetally). Self-pruning (cladoposis) is a well developed process in trees and the rapidity with which it progresses determines the knottiness of timbers. In tolerant (as to light) trees the process may be very tardy. The lateral branches at the base of the crown persist for years and cause knots to form which are exposed to view when the tree is converted into lumber. As long as a branch remains living, a "tight" knot continues to develop which is traceable back through the wood to the pith.* If self-pruning takes place speedily following the death of the lateral branch, the scar is quickly covered over by the cambium and normal wood is thereafter produced centrifugally at that point. In many cases, however, more especially in those trees which have not developed a specialized type of branch-casting through the formation of absciss layers, some time elapses ere the dead stub disappears. The base of the branch or all of the branch-stub may be eventually included in the wood and a "loose" knot results because there is no further growth thickening in the branch after it dies and the seasonal zones of the main axis are not continued into the dead member. "Loose" knots are generally more or less discoloured as compared to "tight" knots and are serious defects of many timbers.

The appearance of knots in lumber varies according to how they happen to be cut. In flat sawn boards, they are seen in transverse or oblique view. The core of the knot may be central but it is generally eccentric and here a peculiar difference is found between the coniferous and dicotyledonous trees. The lateral limbs of the former are thickest on the lower side while the reverse applies in the second group, a peculiarity which may be readily observed on the faces of boards. "Spike-knots," that is, knots cut longitudinally, are features of quarter-sawn lumber and where

* Branches generally arise the second year, rarely the first, as off-shoots from the primary axis. There is an extension of the pith, xylem and phlœm of the primary shoot into the lateral branch and the seasonal zones of branches are attached to the zones formed contemporaneously in the tree so long as the lateral branch continues to live.

the surface exposed is truly radial, the continuation of the knot inward to the pith of the parent stem can be traced without difficulty.*

In grading timber it is customary to classify knots according to size, whether tight or loose knots, and as to the manner in which they happen to be cut. Grading rules vary in different countries and for different kinds of timber and it would be out of place to develop the subject further here.

*Knots may arise from adventitious buds formed on the bole of a mature tree and it follows that the above would not apply in such cases.

PART VI.

Physical Properties of Wood of Value in Identification.

The physical properties of wood may be defined as those properties which are manifest without chemical change. They are in turn divisible into properties which do not require stress for their detection (colour, odour, taste, weight, etc.), and mechanical properties which belong to the realm of the testing engineer and for whose determination elaborate timber-testing machinery is required. The former, since they are readily observed, are of importance in wood identification and are briefly enumerated in the pages which follow.

Colour.

Thin sections of newly formed wood (15 microns)* are whitish in colour and translucent when dehydrated and cleared in oil. As the new wood is left further behind by the advancing cambium (2nd or 3rd year) the colour usually deepens somewhat to a greyish or pale straw-coloured tint, after which there is little or no change until it passes over into heartwood. The sapwood exhibits surprising little colour range.

The significance of heartwood formation was explained on page 44, and many colours are produced which are features of various woods and are of great value in their identification. They range from shades of white and brown through yellow, red, purple and black, and are traceable to infiltration products that are deposited in the wood in varying amount.

Colour may be of advantage or otherwise depending on the manner in which the wood is utilised. For example spruce is the premier pulpwood of the world and has attained that position in part because of its evenness and length of fibre but largely because of the ease with which it is converted into a white pulp of good quality. Coloured heartwood is wanting and little bleach is required to whiten the fibre. Pine in contrast has a pronounced dark heartwood that contains resin in appreciable quantity and hence

* A micron is $\frac{1}{1,000}$ of a millimeter or $\frac{1}{25,000}$ of an inch.

is only suitable for brown kraft-papers. Many of our finest cabinet woods owe their beauty and value to the rich colour of their heartwood which is enhanced through finishing and contributes materially in the form of panels, parquetry, and interior finish of all sorts toward satisfying those aesthetic instincts to which our modern civilization has given birth.

All wood irrespective of heartwood formation deepens or fades in colour on exposure and this has been ascribed to an oxidative process which affects certain colouring matters. But wood as it comes from the living tree, both heart and sapwood, contains large amounts of air which occurs in the form of bubbles in vessels and fills the intercellular spaces (ærenchyma) that always accompany parenchyma. This is constantly being renewed from without and exists in sufficient amount to bring about, ere the tree is felled, such oxidative processes as are capable of inception. The colour change which takes place on exposure is undoubtedly due to photostimulæ of some sort.

The change in colour is often so marked as to be puzzling and requires an understanding of its possible range to avoid error. The heartwood of *toon* is deep brick red in a newly felled tree but ages to a dark brownish red on exposure. The various Indian species of mulberry (*Morus*) exhibit a golden yellow heartwood which deepens gradually to a rich russet brown and comparable changes take place in the *Artocarpus* woods and Andaman padauk (*Pterocarpus dalbergioides*). In fact such darkening is the rule rather than the exception but pale yellow woods such as *haldu* (*Adina cordifolia*) and *papri* (*Holoptelea integrifolia*) are prone to bleach somewhat when first exposed. It is only where the colour change is marked that it is observed.

Changes are sometimes stimulated artificially by chemicals to deepen or darken the colour of wood. Fumed oak darkened by exposure to ammonia fumes is well known in the trade and many tropical woods would undoubtedly respond to the same process.

Finally colour or better said, discoloration, may result from pathologic causes which may be of animal or plant origin. Frequently fungal infection is indicated by dark areas or zones of decay delimited by darker lines. Or bleaching develops either in patches here and there or throughout the tissue which is indicative of the delignifica-

tion of the wood, the residue consisting largely of cellulosic wall substance which in turn may disappear as the deterioration advances. Wood undergoing fungal decay loses weight,* lustre, and resonance, and its mechanical properties are gradually reduced to nil as the fungus spreads throughout the tissue and destroys the cell-wall substance. Distinction should be made, however, between the true "wood destroying" fungi and the "sap-staining" forms. The latter live on the carbohydrate food which is stored in the parenchyma of the sapwood, chiefly in wood rays, and rarely invade the fibrous tissue. Growth is very rapid and the wood may become badly stained in a few hours. Blue stain is very common in fresh sawn lumber, the blue colour resulting from the hyphæ of the fungus as seen *en masse*.

Lustre.

Lustre is the property of wood of reflecting light, in other words, of possessing sheen. The lustre varies with the kind of wood and the plane in which it is viewed. The oily wood of deodar is dull and lustreless in comparison to spruce with its pearly lustre. Cypress (*Cupressus torulosa*) possesses medium lustre when seen alongside of *thitmin* (*Podocarpus neriifolia*), which is dull. Sandal wood, *uriam* (*Bischofia javanica*), teak, and the *Dillenias* are examples of dull dicotyledonous woods, while the other extreme is represented by the *Calophyllums* with their ribbon-grain, *Chloroxylon Swietenia* and *Lagerstrœmia Flos-Reginæ*. The effect is undoubtedly enhanced in the last by the presence of the numerous tyloses which occlude the vessels on the faces of boards and reflect the light strongly, often appearing more or less iridescent under a lens. The presence of oil in quantity in wood (teak) tends to inhibit lustre while lustrous woods are usually comparatively dry (boxwood).

Quarter-sawn timber generally appears more lustrous than flat sawn stock because of the presence of the numerous ray flecks which reflect the light strongly. The figure of quartered oak and *Carallia* owes its beauty to the lustrous ray tissue which is set off against the darker back ground of longitudinal elements. It follows that woods with broad

* Large quantities of water may be present which sometimes lead to an erroneous conclusion. If decayed wood is oven-dried, the decrease in weight is readily detected.

rays are more lustrous in radial section than small rayed woods.

Fluorescence.

Fluorescence is defined in optics as that physical property which some media have of emitting light when exposed to the action of certain rays of the spectrum. Such light is distinct from that reflected at the surface (which gives surface colour) and also from that transmitted by the medium. Aqueous extracts of certain woods exhibit fluorescence and this on occasion may be of secondary value in their identification, but it is an uncertain criterion at best.

A simple test for fluorescence may be made by placing a few grams of saw-dust or wood-chips in a test tube with water and permitting them to stand for two weeks or more, during which time some of the organic infiltration content of the wood leaches out into the water. Fluorescence if present may be detected by filtering the extract into a second tube and examining it in sun light or in the beam of a strong artificial light (projection lamp). The rays of light should be at an angle of about 90° from the point of observation. An effect comparable to that of changeable silk or that observed in tinctures of eosin indicates this property. Fluorescence has been observed incidentally in *Pterocarpus santalinus*, *P. macrocarpus* and *Ougeinia dalbergioides* of the Leguminosæ and *Stephegyne parvifolia* and *S. diversifolia* of the Rubiaceæ but it undoubtedly is a feature to varying degree of many Indian woods.*

Odour.†

Odour or scent as a means of identification must be used with reservation since it does not lend itself readily to description; one is compelled to describe scent by reference to some previously known scent and people vary in their interpretation of odours and in the keenness of their olfactory sense.

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* The Philippine *Pterocarpus indicus* exhibits pronounced fluorescence.

† The senses of smell and taste are akin and it follows that many scented woods (sandal) have taste as well. The "taste" criterion is seldom used in wood identification because it is more fleeting and more difficult of description than odour. It seems unnecessary to elaborate on the subject further in an elementary treatise of this kind.

All wood when freshly cut gives off something of a scent which is not traceable to wall substance itself but rather to the various products infiltrated within it or appearing as deposits in cell or vessel cavities. Numbered among these are ethereal and heavy oils of different sorts, tannins, and certain organic acids and their salts. In the majority of woods the scent is either not sufficiently characteristic or too evanescent to be of diagnostic value. For example the wood of many of the oaks gives off a strong tannin odor when freshly cut but this is of no value in identifying the various species. The wood of *Bischofia javanica* is vinegar scented when first exposed but the odour disappears rapidly as the wood dries. Mal-odours may arise in the sapwood of felled trees from the rapid bacterial decomposition of carbohydrates and proteids contained in the parenchyma cells but scents of this sort have no diagnostic value and usually disappear after a short time as the wood seasons. Fungal decay may often be detected by smell alone and long before discolouration or disintegration of the tissue develops.

It is only when the scent is comparatively strong and lasting and sufficiently characteristic that it possesses taxonomic value. Aromatic woods are no wise numerous and are restricted largely to certain families. Of these sandalwood is best known and may readily be identified by its scent which is striking and easily recognised. Many of the woods of the laurel family (Lauraceæ) possess scents which are more or less characteristic. Camphor wood (*Cinnamomum Camphora*) has the odour of camphor while a strong liquorice perfume emanates from the wood of *Cinnamomum glanduliferum*. The oil of *sassafras* which is used to scent soaps and liniment is the product of another Lauraceous tree (*Sassafras variifolium*), a native of the Eastern United States. Teak possesses an odour which has been compared to that of old leather. *Toon*, satinwood (*Chloroxylon Swietenia*), and *Dysoxylum malabaricum* give off odours that are an aid in their identification and the same applies to some of the species of *Machilus* and *Myristica*. The timbers of *sissu* (*Dalbergia Sissoo*) and blackwood (*Dalbergia latifolia*) sometimes intergrade in color and the only reliable criterion in their determination in such cases is that of odour. The latter is a rosewood, that is, sweet scented while *sissu* is devoid of characteristic smell.

Among coniferous woods scent is often evident and is of value in identification. The pungent aromatic odour of

deodar is familiar to most Indian foresters. Cypress (*Cupressus torulosa*) and cedar (*Juniperus macropoda*) give off a cedar odour which is the stronger in the first species. Spruce is odourless as compared to pine and the various species of *Pinus* differ in this respect; the hard pines usually exhibit a stronger resinous odour than soft pines and may sometimes be identified by this feature alone.

Odour may enhance or detract from the value of a wood for specific purposes. Oak is the standard wood for gin casks. Pine does not prove a good substitute as the alcohol dissolves out appreciable quantities of resin and a turpentine odour and taste are communicated to the gin. Ash and fir (*Abies*) are favorite woods for butter tubs because of their absence of scent. Red cedar is prized for chests as the presence of cedar oil in the wood tends to keep away moths. Cigars are supposed to improve in flavour if packed in boxes of Spanish cedar (*Cedrela odorata*). On the other hand the use of certain woods in the manufacture of containers of various sorts is precluded because of odours, which, while not directly offensive, prove so when communicated to edible products.

Weight of Wood.

The weight of wood depends on its density, its moisture content, and the organic and mineral infiltration products that are in no sense a part of the wood itself but are deposited in cell walls and cell cavities. Since the weight factor has an important bearing on wood utilisation and especially is this true of heavy tropical timbers, a cursory summation of its more pertinent features are given in the paragraphs which follow.

(*a*) *Density versus Weight.*

As was pointed out on page 17, the cell walls of the higher plants are remarkably uniform in their chemical structure. They consist largely of cellulose in which as a matrix other compounds are infiltrated; the organic complex lignin in the case of woody tissues. Lignified cell walls conform to their cellulosic progenitors in being remarkably uniform in chemical constitution and hence in weight per unit of volume. The wall substance of lignified cells, irrespective of the kind or source of wood, is approximately 1·6 times as heavy as water. Oven-dried woods are

light or heavy not because of the variation in the composition of wall material but rather because of the amount of that material that is present per unit of volume (density).*

The density of wood varies directly as to (1) the size of cells and (2) the thickness of cell walls. Coarse-textured woods such as *semul* are light because their cell walls are comparatively thin. Fine-textured woods may remain light in weight (*Trewia nudiflora*) owing to thin-walled fibrous tissue or become heavy because the thickening in fibrous cells is pronounced and but small lumina remain (*Olea ferruginea, Mimusops Elengi*). There is apparently a definite relation between large cells and restricted wall thickness as coarse textured woods tend to remain light, but exceptions to this rule occur as for example *Bischofia javanica* and *Bridelia retusa* which possess coarse-textured fibrous cells but are of medium weight. The reverse does not apply as both light and extremely heavy woods are numbered among those of fine texture.

(*b*) *Moisture Content* versus *Weight.*

The moisture content of green wood may be several times its dry weight*[1] and exists in three ways in the tissue, namely :—

(*i*) as free water in cell cavities and vessels,
(*ii*) as water of imbibition in cell walls, and
(*iii*) as making up ninety-five per cent. of the protoplasts of the parenchyma cells of the sapwood.

Of these the first two are of most significance in the utilisation of wood.

Free water is found in the cavities of cells and vessels but rarely if ever completely fills them. For example the vessels of a dicotyledonous tree contain air at all times, even at the height of the growing season, which generally forms bubbles surrounded by films of water (Jamin's chains). It is surprising the amount of air that can be drawn out of some green woods with a suction pump. But where the air is restricted in amount or reduced in volume

* The buoyancy of woods in water is due to the air imprisoned within cell cavities. If this is drawn out with a suction pump, the lightest woods sink as readily as those of the heavy dense type.

*[1] It is customary to express the moisture content of wood in terms of its oven-dry weight. The following formula may be used to obtain the moisture percentage of wood.

$$\text{Moisture percentage} = \frac{\text{Wt. of green wood} - \text{Wt. of oven-dry wood}}{\text{Wt. of oven-dry wood}} \times 100.$$

through compression, the moisture content may run very high, as high as two hundred per cent. in some cases, and the bulk of this (all over 30 per cent.) is traceable to free water contained in cell and vessel cavities.

The water of imbibition is confined to cell walls, that is, to wall substance, and makes up roughly thirty per cent. of the weight of green wood. The ability of wood to take up and hold moisture is known as its hygroscopicity and is due to the fact that the ultra-microscopic particles of cell wall substance are surrounded by films of water which reach their ultimate diameter at about 30 per cent. moisture content. No shrinkage occurs in wood above the wall-substance saturation point, that is, the fibre saturation point. When logs are sawn into boards and the latter are exposed to the air, the free water in the wood is the first to disappear*—followed by some of the water of imbibition. But the last continues to evaporate more and more slowly as the quantity is reduced and the films of water about the wall particles become thinner; the wall substance clings to its moisture and may be likened to an extremely fine clay soil in this respect. Air seasoning if continued will ultimately result in a reduction to 8—12 per cent. of moisture but the actual moisture content of unprotected wood when exposed to the air fluctuates constantly with temperature and humidity. The wide extremes of humidity in India is one of the bugbears of wood utilisation.

The remaining wall moisture content can only be driven off by artificial (kiln) drying and an absolutely dry condition is not desirable, even for wood which is utilised under comparatively dry conditions; generally from five to ten per cent. of moisture is left in the tissue. Moisture continues to come out of wood up to temperatures of 100°C. and even above that point which is in part due to the tenacity of wall-substance for water, but dry distillation of infiltration products may begin below the boiling point and chemical changes ensue, resulting in the formation of additional (new) moisture. It is customary, however, to consider the oven-dry condition as a "constant" in the compilation of tables of weight for wood.

Living protoplasts are found in wood parenchyma, both longitudinal and ray parenchyma, as long as it is a part of the sapwood and water enters into the composition of

* Case hardening may result.

protoplasm to the extent of 95 or more per cent. of its weight. The parenchyma content of sapwood varies widely in different trees and it is surprisingly high in some cases. Some inkling of this may be gleaned by referring to tables of ray volume. Ray volumes run from 2—11 per cent. for coniferous woods and as high as 40 per cent. in some of the oaks, and this takes no account of the longitudinal parenchyma which is abundant in many dicotyledonous woods (the oaks included). Owing to the fluid nature of protoplasm no exact figure can be given as to the relative amounts of free and of protoplasmic water in sapwood. This does not hold for heartwood since living protoplasts have entirely disappeared and all moisture above the fibre saturation point must be considered as free moisture.

(c) *Infiltration Content* versus *Weight.*

The mineral matter in wood and its organic infiltration content are no wise as important in their bearing on weight as water. The former is left behind in the ash when wood is burned and seldom makes up more than one or two per cent. of the total figure. Silicon and the carbonates, silicates, and oxalates of calcium are the most abundant and are found either in the amorphous or the crystalline condition. Crystals of calcium oxalate are features of many woods (*Soymida febrifuga*, *Albizzia procera*, etc.), being set aside in special parenchyma cells or idioblasts, as they have been termed. When copious in amount, organic infiltration may affect the weight of wood materially and particularly is this true of trees with dark heartwood such as ebony (*Diospyros Ebenum*) and red sanders (*Pterocarpus santalinus*). Such heartwood is no stronger than the neighboring sapwood under given conditions of moisture but it may be a number of times heavier.

(d) *Manner in which the Weight of Wood is Expressed.*

The weight of wood is expressed in various ways according to convenience or the manner in which the wood is utilised. For example, it may be in pounds per cubic foot or by specific gravity, the last a ratio which indicates the weight of the wood as compared to the weight of a like volume of

distilled water at its greatest density.* The equation is as follows :—

$$\text{Specific gravity of wood} = \frac{\text{Weight of wood.}}{\text{Weight of a like volume of distilled water.}}$$

But the weight of a given piece of wood fluctuates with varying moisture content irrespective of density or infiltrations and it is necessary to take the weight under constant conditions where comparisons are to be made. It is customary to oven-dry the wood at a temperature of 100° C. until it ceases to lose weight and the results of the final weighing are used in the formula. The volume of the wood may be obtained at different points in the drying process. For example, specific gravity may be based on volume when green, that is, above the fibre saturation point, volume when air dry (8—15 per cent. of moisture), or volume when oven-dry. Specific gravity based on " volume when green " and " oven-dry weight " is considered to best indicate the mechanical possibilities of the wood and unless otherwise stated this is the manner in which the ratio is obtained. Since one cubic centimeter of distilled water at its greatest density weighs one gram, the specific gravity of a timber can be obtained without the use of conversion factors, by taking the weight of the wood in grams and its volume in cubic centimeters.

Where the specific gravity of a wood is known, its weight per cubic foot can be readily computed by multiplying this by 62·43 since this is the weight of a like amount of distilled water. Suppose for example the specific gravity of a wood was $\cdot 42 = \frac{42}{100}$; then 62·43 lbs. $\times$ ·42 = 26·22 lbs. (weight of the wood per cubic foot). Since the majority of woods are lighter than water, specific gravity is usually represented by a decimal of two figures. Woods heavier than water have specific gravities of 1·00 etc.

In addition to the above, the weight of wood may be expressed in pounds per thousand running (English)† or board (American) feet. Such figures are of value in computing the weight of lumber where it is shipped by boat or in car load lots. A peculiar condition has arisen in India in that wood is sold by the ton but this term has

* Distilled water reaches its greatest density at 4° C.; a cubic foot of distilled water at this density weighs 62·43 lbs.

† A " running " or " board " foot is one foot square and one inch thick.

come to be a measure of volume. Fifty cubic feet are considered a ton (2,240 lbs.) because this is the approximate weight of that quantity of Burma teak wood and the usage of the term has spread to other woods as well.

(*e*) *Relative Weights of Indian Woods.*

Indian woods vary remarkably in weight under standard conditions of moisture and this is traceable to density and infiltration products. The determination of the specific gravity of all the Indian commercial species is underway at the Forest Research Institute*[1] but this information is not available at the present time. An idea of the relative weights of the principal Indian timbers may be gleaned from Troup's list*[2] which, however, is based on air-dry weight.

Classification of Indigenous Woods according to their Weight in Pounds per Cubic Foot.

(*i*) Extremely heavy.—70 lbs. and over.—*Hardwickia binata, Tamarindus indica, Pterocarpus santalinus, Soymida febrifuga, Diospyros Ebenum, Mesua ferrea.*

(*ii*) Very Heavy.—60 lbs. and over, and under 70 lbs.—*Pterocarpus indicus, Schleichera trijuga, Heritiera minor, Acacia Catechu, Xylia dolabriformis, Quercus dilatata, Q. incana, Anogeissus latifolia, Bassia latifolia, Santalum album, Terminalia tomentosa, Shorea obtusa.*

(*iii*) Heavy.—50 lbs. and over, and under 60 lbs.—*Pterocarpus macrocarpus, Cassia Fistula, Prosopis spicigera, Chloroxylon Swietenia, Dalbergia latifolia, Melanorrhoea usitata, Buxus sempervirens, Dipterocarpus tuberculatus, Pterocarpus Marsupium, Shorea robusta, Acacia leucophloea, Ougeinia dalbergioides, Acacia arabica, Terminalia Chebula, Quercus semecarpifolia, Lagerstrœmia parviflora, Melia indica, Albizzia Lebbek, Dalbergia Sissoo, Odina Wodier, Careya arborea, Chickrassia tabularis, Grewia tiliaefolia.*

(*iv*) Moderately heavy.—40 lbs. and over, and under 50 lbs.—*Hopea odorata, Dipterocarpus turbinatus, Zizyphus Jujuba, Pterocarpus dalbergioides, Terminalia belerica,*

*[1] The determination is based on oven-dry weight and volume, volume being determined by immersion in mercury in a special apparatus which accommodates a block approximately two cubic inches in size.

*[2] Indian Forest Utilisation, Indian Govt. Pub., pp. 16—18, 1907.

Eugenia Jambolana, Dipterocarpus alatus, Lagerstrœmia Flos-Reginæ, Tectona grandis, Adina cordifolia, Dillenia indica, Aegle Marmelos, Pinus longifolia, Taxus baccata, Schima Wallichii, Juglans regia, Sterculia urens, Mangifera indica, Anthocephalus Cadamba, Artocarpus integrifolia, A. Lakoocha.

(*v*) Light.—30 lbs. and over, and under 40 lbs.—*Butea frondosa, Cupressus torulosa, Michelia Champaca, Semecarpus Anacardium, Cedrela Toona, Gmelina arborea, Ficus bengalensis, Boswellia serrata, Kydia calycina, Pinus excelsa, Cedrus Deodara, Aesculus indica, Michelia excelsa, Artocarpus Chaplasha, Buchanania latifolia, Sterculia alata, Picea Morinda, Abies Pindrow, Ficus glomerata.*

(*vi*) Very light.—Under 30 lbs.—*Trewia nudiflora, Populus ciliata, Duabanga sonneratioides, Spondias mangifera, Bombax malabaricum, Ailanthus excelsa, Sterculia colorata, Tetrameles nudiflora, Erythrina suberosa, Moringa pterygosperma, Sterculia villosa, Cochlospermum Gossypium.*

(*f*) *The Importance of Weight in the Utilisation of Wood.*

The weight of wood has an important bearing on utilisation and particularly is this stressed where substitutes are sought for a given species. Many of the woods which have become standard for special purposes have been in use so long that the qualifications which recommended them originally have been well nigh forgotten and the wood continues to be used without thought of its anatomical structure and physical properties. But in seeking substitutes, a difference of a few pounds in weight per cubic foot is often sufficient to condemn the wood for a specific purpose. It may have the requirements of texture, of hardness, of colour, etc., but the effect of additional weight as expressed in greater " load " cannot be overcome by other factors, no matter how favourable. Weight is of foremost importance in the utilisation of wood for many purposes.

PART VII.

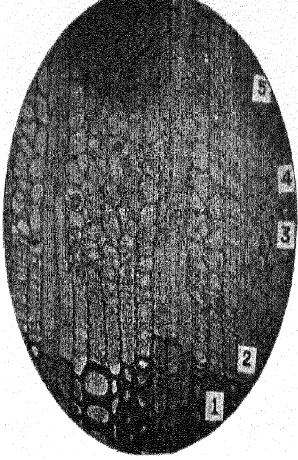
The Microscopy of Wood.

Under the microscopical features of wood are included those which are discernible only at high magnifications (40 × or more). The microscopical examination of woody tissue represents the ultimate in a study of its anatomy and identification and is important because many of the technical properties of timber are traceable directly to its structural features.

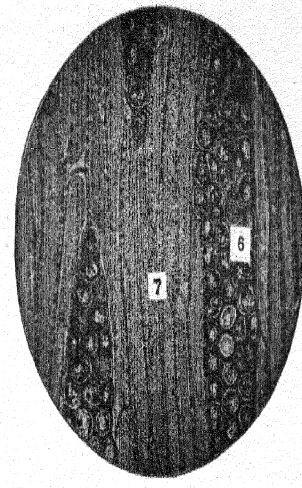
The Cambium.

All the wood of a tree stem aside from a small amount immediately coterminous to the pith results from cell division in the lateral meristem or cambium, that is, it belongs to the secondary tissues. The majority of texts which deal with wood anatomy usually contain little information as to this ultimate source of wood and a number of puzzling questions are therefore left unanswered. Since cambial studies offer a natural approach to the subject in hand and render lucid many points that might otherwise confuse, a number of paragraphs are devoted to them.

Figure XIX shows the salient features of the resting cambium of teak as seen in transverse, tangential and radial section. In A the last formed wood (1) may be seen at the bottom of the photograph and consists of a radial row of three summerwood pores, a number of fibrous mechanical cells, and two wood rays which pass out into the phloem. The cambium (2) extends from right to left and is made up of about eight rows of tabular cells between the wood rays but of only three or four in the wood rays proper. An initial or primary row cannot be distinguished with certainty and this is the condition in the growing layer of all trees. The last formed soft bast (phloem) follows the cambium in peripheral sequence (3) and the sieve tubes, accompanied by small companion cells at the corners, are clearly shown, followed toward the outside by large thin-walled cells which simulate sieve tubes but lack companion cells, the phloem parenchyma (4). Finally, there is a tangential band of thick-walled bast fibres (5) whose function it is to protect the delicate soft bast tissues.



A



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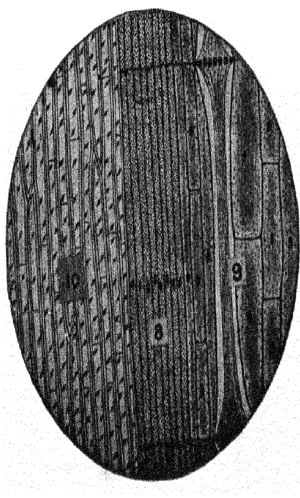

Figure XIX —Dormant cambium of teak in cross (A), tangential (B), and radial (C) section A_1, Last formed wood, A_2, The cambium consisting of 8-10 rows of tabular cells, A_3, Sieve tubes and companion cells, A_4, Phloem parenchyma cells, A_5, Bast fibres, B_6, Wood ray cambial initials, B_7, Fusiform cambial initials, C_8, Cambium in radial view, C_9, Phloem elements consisting of sieve tube, companion cell, and phloem parenchyma cells

C

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Figure XIX, B depicts the cambium in longitudinal tangential section, and two types of cambial mother cells are to be seen, those which give rise to wood rays (6) through periclinal division (in the plane of the paper) and fusiform elongated initials (7) to which the longitudinal xylem elements of teak are traceable. The deduction is obvious that all the longitudinal elements of the wood (that is, the vessels, rows of parenchyma cells, and fibres, to be described subsequently) owe their origin to the same type of mother cell in the cambium. The wide morphological distinctions which distinguish these in the mature wood are wholly of post cambial origin.

Figure XIX, C, 8 represents the cambium diagrammatically as it would appear in radial section. It now is seen to be of storied structure and the cells of each row are of common lineage, being descendants of the same mother cell. This seriate-echelon arrangement is always a feature of the radial sections of the growing layer of timber trees owing to the nature of the cell divisions in the cambium.* It is continued out into the phloem to the right (9) but is not evident in the xylem to the left (10) owing to the fact that the fibrous elements of teak elongate greatly following their formation in the lateral meristem.

General Shape and Gross Dimensions of Wood Elements.

The cells which are cut off centripetally by the cambium eventually become a corporal part of the wood but ere this occurs, certain changes take place whereby the different types of wood elements are evolved. By far the majority of the cells elongate in a direction which is most labor-saving in relation to the functions which they are compelled to perform. The daughter cells arising from division of the ray initials lengthen radially until they are a number of times as long as wide. Then follows a period of thickening and typical ray units develop. Coniferous and dicotyledonous woods are peculiar in that they do not register striking differences in the relative dimensions of ray cells but wide extremes in ray size (see plates at the back of the text). High or wide rays owe their origin not to component

* It follows that in woods which exhibit ripple marks on tangential section, the cambial initials are storied as viewed tangentially. Both the ray and vertical cambial initials may be concerned or the echelon alignment may be confined to the one or the other type.

cells of large size but rather to an increase in the number of cells which enter into the ray structure.

As was pointed out on page 74, all the longitudinal elements of teak wood arise from the same type of fusiform ray initials and the wide extremes which are found in their structure and size are of post cambial development. The longest (mechanical) cells of a wood always belong to the fibrous type and there a striking difference is to be noted which distinguishes non-porous and porous woods.

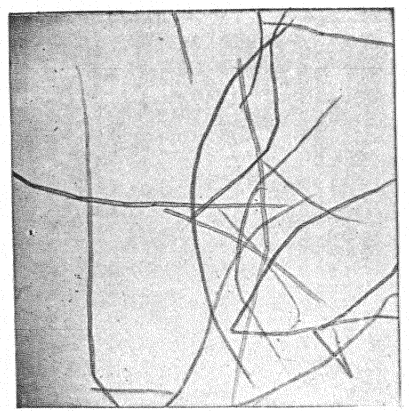
Figure XX shows photomicrographs at the same magnification, of the fibres of *chir* and teak and it is evident that those of *chir* are much the longer. The average length of the fibres of the various Indian conifers varies from 1·4 to 7 millimeters* and is longest in the coarse textured wood of *Pinus Merkusii.* Porous woods on the other hand are without exception relatively short fibred (1—2 millimeters). This accounts for the fact that hardwood is not productive as a source of pulp and paper since the short fibred cells do not mat well.

The elongation of fibrous cells following their origin in the cambium is significant in its bearing on the ultimate strength of wood and the extent to which it proceeds is seldom appreciated by students of wood anatomy. Dicotyledonous trees offer the best opportunities for investigation because their cambial initials are much shorter than those of the conifers. Some figures may prove illuminating as bearing on this point. For example the average length of the longitudinal cambial cells of teak as shown in Figure XIX, B was 334 microns; the average length of the fibrous cells immediately coterminous to them in the wood was 1,240 microns. Elongation had occurred to the extent of over three hundred per cent.; in other words the mature fibres of teak are more than three times as long as the cambial initials from which they arise.

It would be erroneous, however, to arrive at the deduction that sliding growth always proceeds to the same degree as that of teak. Undoubtedly it will be found to be much less in other dicotyledons and in coniferous trees. Mischke,† a German investigator, claims it to be but 25 per cent. during the formation of spring wood in Scotch pine *Pinus*

* See table on page 83.

† Mischke, Karl Beobachtungen uber das Dickenwachsthum der Coniferen, Botanisches Centralblatt, Vol. 41, pp. 39—96.



Photomicrographs by H. P. Brown.

CHIR TEAK

Figure XX.—Photomicrographs illustrating fibres of *chir* and teak.

[To face page 76].

sylvestris) with a fall to 20 per cent. in the summer wood zone.* But coniferous trees are characterized by very long longitudinal cambial initials and the daughter fibrous cells (tracheids) arising from these are much longer than the fibres of dicotyledonous woods, in spite of restricted sliding growth in the former. It would seem that in the evolution of porous wood which is to be regarded as a modern type, the ultimate effect of the shortening of longitudinal cambial initials occasioned by reasons as yet unexplained has been offset in part at least by an increase in the extent of the sliding growth in daughter cells following their formation.

The remaining longitudinal elements of wood which are described in detail in the pages that follow are always much shorter than the fibres with which they are associated. In some cases a certain amount of elongation takes place as they mature behind the cambium, in others the mature cell enlarges greatly in diameter (vessel-segments) without appreciable longitudinal stretching, or but widens its lumen slightly ere becoming incorporated into the wood. In addition cross walls may form at intervals as the elements mature,† and in many cases the fusiform nature of the cambial initials is permanently registered in the wood through rows of parenchyma cells (oak) with tapering ends or by tracheids in the neighbourhood of vessels (oak).

The lengthening of wood cells following their origin in the cambium has been described as "sliding growth" and two possibilities are presented. Elongation may be regional and restricted to the ends of the elements or it may ensue throughout their whole length. In either case the phenomenon is best explained if the supposition is entertained that the walls of the embryonic cells consist of three layers, the middle of which is of a gelatinous nature permitting of the sliding of lateral layers, one upon another. Such a condition may be illustrated if grease is placed upon a window glass and a second glass applied. The one will then slide upon the other but they may be pulled apart only with difficulty. An examination of the radial walls of the cambial cells of teak under high magnifications supports the inference as to the gelatinous nature of the middle wall layer since a tandem stratification is discernable, separated by a layer of a different composition.

* More recent evidence indicates that the sliding growth of conifers is seldom over one per cent.

† Teak wood contains septate fibre tracheids, the cross walls of which arise after these elements are formed in the cambium.

The Elements of Chir *Wood.*

The cells of *chir* wood are shown diagrammatically in Figure XXI, drawn to a scale of 180 microns* = 1 inch. Those which have their long axes arranged vertically in the plate constitute the longitudinal elements of the wood while ray elements extend from right to left. All are shown in radial view.

The long cell which extends about the periphery of the figure (1) is a tracheid with its bordered pits and is typically prosenchymatous. The tracheids of *chir* wood average 3·87 millimeters in length and ·063 millimeters in width tangentially; in other words they are over sixty times as long as wide. Coniferous woods are always characterized by very long tracheids and the figures of text books are generally misleading in this respect.

The number of bordered pits to a tracheid runs surprisingly high. Eighty-four are shown in the figure but these are confined to but the one radial wall and are most numerous near the ends of the tracheid. Fully as many undoubtedly are present on the other radial wall which would run the figure up to one hundred and sixty-eight. *Chir* is a "hard" pine and bordered pits do not appear on the tangential walls of its tracheids; the total average count of pits may be estimated as between 150 and 200.

The number of tracheid pits undoubtedly runs much higher in other coniferous woods. For example *Pinus Merkusii* has fibrous cells which average 7 millimeters in length and a strong tendency toward a paired condition of the pits is to be noted, especially toward the ends of the tracheid, which results in a decided increase in their number. The other Indian conifers aside from the hard pines are featured in addition by tangential pitting on summerwood tracheids and this tends toward an increase in the ultimate figure. It may be inferred that the pit count is well over three hundred, in some cases at least.

A further feature of the bordered pit as seen in surface view is the presence of arcs concentric to the outer circle of the pit, one on either side above and below. These have been named "Bars of Sanio" after one of the earlier anatomists and are occasioned by thickenings in the primary

* 1 micron equals 1/1,000 millimeter equals 1/25,000 inch.

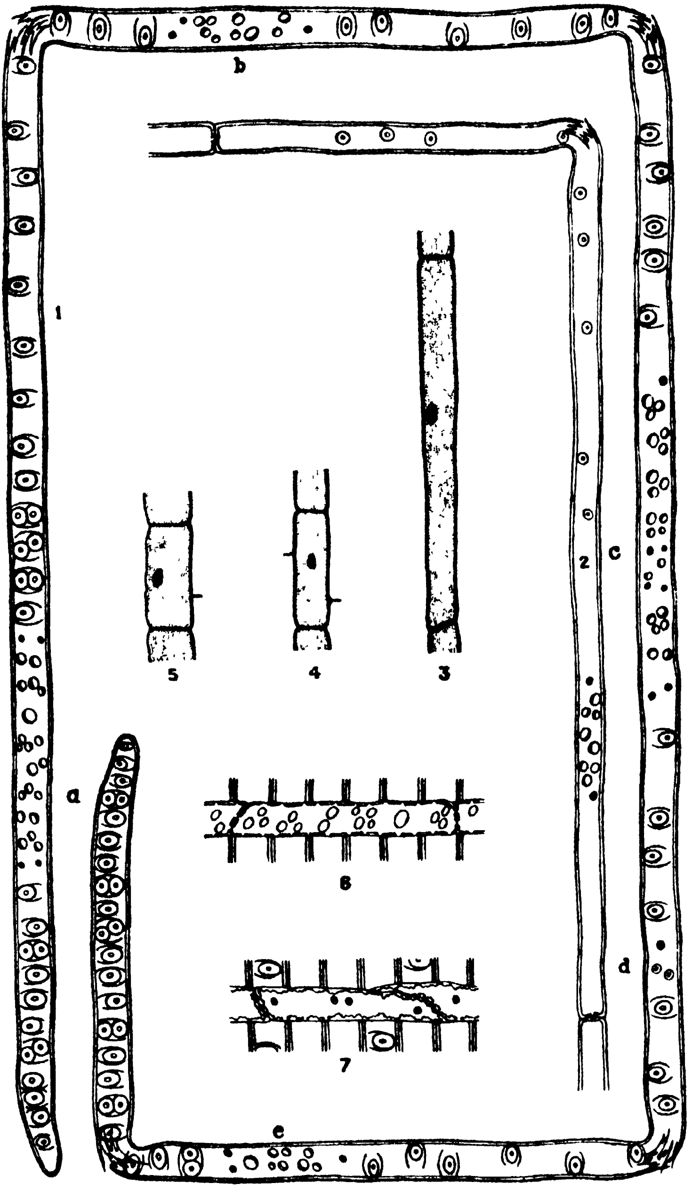


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Figure XXI.—Elements of *chir* wood *(Pinus longifolia)*, drawn in lateral aspect to a scale of 180 microns = 1 inch. 1, Tracheid ; 2, Parenchyma tracheid ; 3, 4, 5, Epithelial parenchyma cells ; 6, Ray parenchyma cell ; 7 Ray tracheid.

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[To face page 78.

lamella underlying the secondary wall-layer (toward the observer). Since their morphological significance yet remains to be explained and as they possess no diagnostic value*, they are not deserving of more than mention here.

The letters along the margin of the tracheid indicate the points where it comes in contact with wood rays. Two types of pits are in evidence here, those which are of the small bordered type and semi-bordered pits of somewhat larger size. The significance of these will be explained subsequently. The chief point of interest is that the tracheid was in contact with wood rays at five places on one side. The number may safely be doubled when the other radial wall is taken into consideration and this serves to bring out the intimate relation which exists between tracheids and wood rays throughout the wood.

Number 2 is that of a parenchyma tracheid, that is, of an element transitional between a tracheid and a vertical parenchyma cell. It possesses the bordered pits of the former and an identical physiological feature, namely, that it loses its cell contents very quickly following formation in the cambium. The shape, however, is that of an elongated parenchyma cell with end walls at right angles to the longitudinal. *Chir* wood possesses resin canals and parenchyma tracheids represent a transition type of element between the secreting cells which immediately surround the resin cavity and typical tracheids; they are always confined to the vicinity of the resin canals in pine wood.

Numbers 3, 4 and 5 depict the various types of epithelial parenchyma as the resin chamber is approached. The cells are shown with nucleus and cytoplasm since they remain living as long as they are included in the sapwood. The shorter units are immediately coterminous to the resin cavity and the transition to the tracheid is in the sequence shown in the figure, namely, short resin parenchyma cells, elongated parenchyma cells, parenchyma tracheids, and true tracheids, respectively.

The short horizontal cells at the base of the figure indicate the two types of elements that enter into the structure of the wood rays of *chir*, namely, the ray parenchyma cells (6) and ray tracheids (7). The latter are so designated owing to the fact that they simulate the longitudinal tracheids in structure and function. They are typically prosenchyma-

* Bars of Sanio are constant features of coniferous woods.

tous, possessing bordered pits and losing their protoplasmic contents quickly following formation in the cambium. Ray tracheids are concerned chiefly in the radial conduction of water. The ray parenchyma cells in contrast possess simple pits, remain living as long as they are a part of the sapwood, and conduct and store carbohydrate food. The body of the *chir* ray is made up of ray parenchyma cells while ray tracheids are typically marginal but may become interspersed as well, especially in high rays. On the other hand where the height of the ray is restricted to one or two cells, the parenchyma is completely eliminated and the ray consists entirely of tracheal cells.

Microscopic Structure of Chir *Wood.*

The general features of *chir* pine wood in transverse section are shown in Figure XXII. From the small " insert " it is evident that the seasonal zones are distinct. Two uniseriate rays extend from the bottom to the top of the large photograph and a third runs out to the right because the plane of section was not exactly transverse and wood rays in the tree stem run parallel to the surface of the ground. Aside from a large resin canal which is closely invested with secreting epithelial parenchyma (epithelium), the space between the rays is occupied by tracheids, the thick-walled squarish or rectangular tracheids of the summerwood of one ring passing over abruptly into the wide lumened, thinner-walled and somewhat polygonal springwood tracheids of the following season.* A radial alignment is to be observed throughout because the tangential diameter of the tracheids remains nearly constant, new rows being inserted as the increasing ring periphery warrants it. Dense summerwood is formed through a thickening in tracheid walls and a reduction in their radial diameter. The primary lamellas of the various cells are conspicuous with secondary layers which were deposited upon them from within while the protoplast was still living. Bordered pits in sectional view are numerous in the radial walls, especially in the springwood tissue, and intercellular spaces between tracheids may be detected in the lower right hand corner.

Figure XXIII gives the general aspect of the wood in the longitudinal radial section and was purposely selected

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* The radial rows of smaller units are indicative of tracheids cut transversally at their tapering ends.

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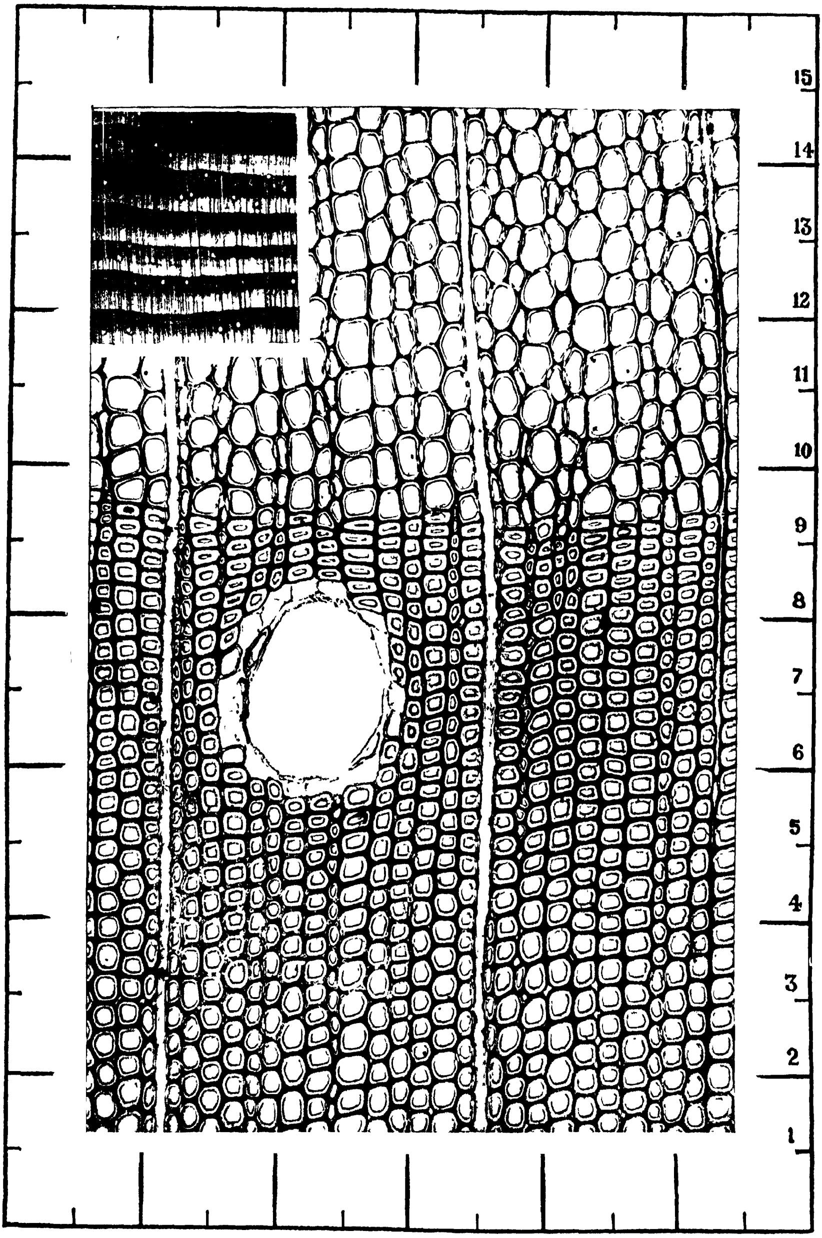

Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

Figure XXII.—Photomicrograph illustrating the structure of *chir* wood (*Pinus longifolia*) as seen in transverse section.

[To face page 80.]

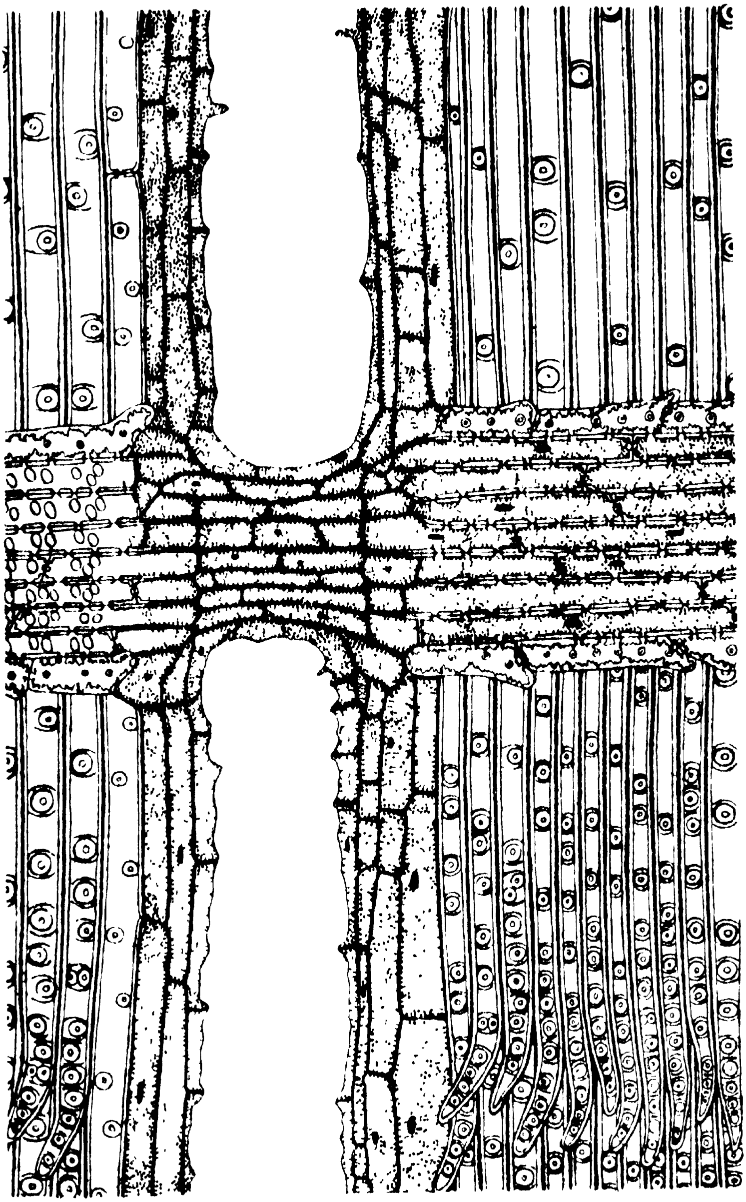

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Figure XXIII.—Schematic drawing illustrating the structure of *chir* wood (*Pinus longifolia*) as seen in longitudinal radial section.

[*To face page 81.*

to show the relation of the wood rays to the longitudinal tracheids and resin canals. One of the latter extends vertically in the drawing and a wood ray sweeps across from left to right and is "cupped" around the resin canal. Three or four rows of epithelial cells sheath the resin cavity, the outer being much the longer and giving place to parenchyma tracheids, and eventually to tracheids to the right and left. The terminations of a radial row of tracheids are shown at the bottom of the figure and appear in the plane of section because they are all descendants of the same mother cell in the cambium. Since the ray is seen in lateral surface view the dual nature of its cells show to advantage. The ray tracheids with their dentate thickening and bordered pits form a single row on the margins and seven rows of ray-parenchyma cells occupy the middle portion of the structure. Greater detail is achieved in that the ray cells are shown in lateral surface view; to the right, the parenchyma cells with nuclei and cytoplasm, and in lateral sectional view to the left with their numerous pits. In this connection it should be noted that both sorts of ray cells are replaced by resin parenchyma where they actually come in contact with the resin cavity.

Epithelial cells and ray parenchyma belong to the general category of parenchyma. They are characterized by simple pits or a complete absence of pits and by living contents, and remain alive as long as they are a part of the sapwood. Tracheids, parenchyma tracheids, and ray tracheids are typically prosenchymatous with bordered pits but without protoplasmic contents. Longitudinal and ray tracheids are in communication through bordered pits and the same holds true where ray tracheids or longitudinal tracheids are coterminous. Ray parenchyma cells in contrast communicate with each other by means of simple pits but the pits that lead laterally into the longitudinal tracheids are semi-bordered, simple on the side toward the ray, bordered on the tracheid side. This again is but a confirmation of the statement that parenchyma cells are characterized by simple pits (or an absence of pits where the walls are thin) while prosenchyma cells are featured by bordered pits. Where the one type of cell abuts on the other, a semi-bordered condition results.

There remains but the discussion of the features of *chir* wood as seen in tangential section and these are illustrated by Figure XXIV. The back (tangential) walls of longi-

tudial summerwood tracheids are shown diagrammatically in the lower right hand corner while above, the section invaded the more open springwood of the following season and was of requisite thinness to eliminate entirely both the front and back tracheid walls. The chief features which distinguish the tangential from the radial section is the change in the appearance of the wood rays, the shift in the orientation of bordered pits from a surface to a sectional view, and the more pointed ends of the tracheids which no longer end at approximately the same height.*

The wood rays of pine are in the main uniseriate and vary in height from one to a dozen or more cells. Ray parenchyma communicates with longitudinal tracheids to the right and left by means of semi-bordered pits while bordered pits characterise the marginal ray tracheids. A further feature is in evidence which generally accompanies ray cells, namely, intercellular spaces at the corners that undoubtedly provide the oxygen which is necessary for the vital activities of all living cells. Two horizontal resin canals appear as inclusions in rays which have become spindle shaped or fusiform as a result. Such horizontal canals are constant features of *chir* wood and communicate with those of the longitudinal type to form the resiniferous system of the xylem.

The bordered pits are very numerous on the radial walls of the longitudinal tracheids and there is a marked increase in their numbers near the pointed tracheid ends. The valve-like nature of the pit is seen to advantage, the torus or plug occupying a median position since the section is taken from the sapwood.† A surface view of bordered pits is not afforded since tangential pitting is entirely wanting on the tracheids of the "hard" pines to which *chir* belongs. It is, however, a constant feature of the summerwood tracheids of "soft" pines (*Pinus excelsa*) and in fact of all other coniferous woods.

Resumé of the Microscopical Features of Indian Coniferous Woods.

Coniferous woods are remarkably uniform in structure which is indicative of the fact that this type of tissue was

* Each tracheid as seen in tangential section has descended from a different cambial initial; in other words they are not daughter cells but single units in a radial row extending toward the observer.

† The tori in the pits of "heartwood" tracheids are pushed either to the one or the other side and effectively close the pit orifice.

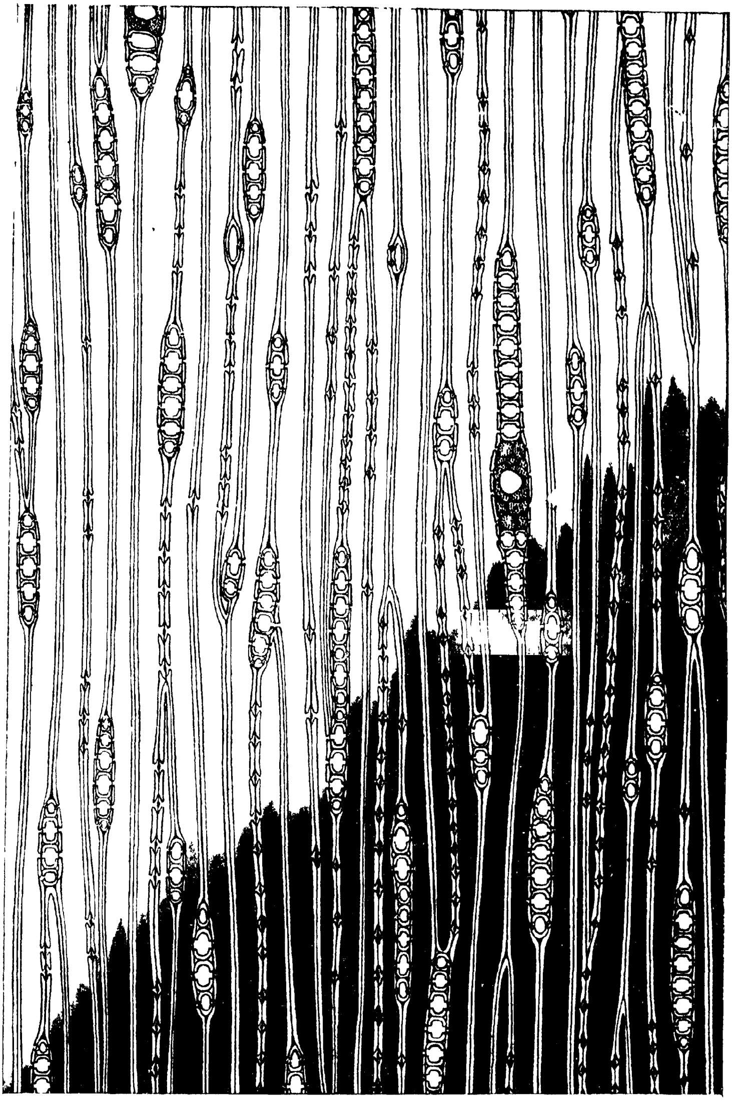

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Figure XXIV.—Schematic drawing illustrating the structure of *chir* wood (*Pinus longifolia*) as seen in longitudinal tangential section.

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TABLE OF ANATOMICAL FEATURES OF INDIAN CONIFEROUS WOODS *₁

SCI. NAME	LENGTH OF TRACHEIDS MIN AV. MAX	BORDERED PITS ON RADIAL WALLS OF TRACHEIDS 1 SERIATE	BORDERED PITS ON RADIAL WALLS OF TRACHEIDS 1 2 SERIATE	BORDERED PITS ON TANG WALLS OF TRACHEIDS	AVERAGE TANG DIAM OF TRACHEIDS	TRACHEIDS WITH TERTIARY SPIRALS	LONGITUDINAL WOOD PARENCHYMA	RESIN CANALS NORMAL	RESIN CANALS TRAUMATIC	RAY HT *₂ IN CELLS MIN AV MAX	WOOD RAYS *₂ 1 SERIATE	WOOD RAYS *₂ 1-2 SERIATE	RAY TRACHEIDS MARGINAL	RAY TRACHEIDS INTERSPERSED	RAY TRACHEIDS EVEN	RAY TRACHEIDS DENTATE
ABIES PINDROW	1·6(3·9)5·5	——	X—	X	33μ	——	SPARSE; TERMINAL	——	——?	1(7)21	X	——	——	——	——	——
CEDRUS DEODARA	·4(3·4)4·7	——	X—	X	31μ	——	SPARSE, TERMINAL	——	X	1(17)43	——	X—	X	——	X	——
CUPRESSUS TORULOSA	1·7(2·9)4·4	——	X—	X	29μ	——	ABUNDANT, META-TRACHEAL ZONATE	——	——	1(13)51	——	X—	——	——	——	——
JUNIPERUS MACROPODA	1·6(2·1)2·8	X	——	X	23μ	——	META-TRACHEAL DIFFUSE	——	——	1(4)11	X	——	——	——	——	——
JUNIPERUS RECURVA	·9(1·2)1·6	X	——	X	17μ	——	META-TRACHEAL ZONATE	——	——	1(2)6	X	——	——	——	——	——
LARIX GRIFFITHII	2(3·6)4·9	——	X+	X	36μ	——	SPARSE, TERMINAL	X EPITHELIUM THICK-WALLED	——	1(9)28	——	X—	X	X—	X	——
PICEA MORINDA	1·7(3·3)4·9	X	——	X	30μ	X	SPARSE, TERMINAL	X EPITHELIUM THICK-WALLED	——	2(7)22	X	——	X	X—	X	——
PINUS EXCELSA	2·3(3·3)5·3	X	——	X	30μ	——	——	X EPITHELIUM THIN-WALLED	——	1(6)12	X	——	X	X—	X	——
PINUS GERARDIANA	2·4(3·5)5·3	——	X+	——	35μ	——	——	DITTO	——	1(6)26	X	——	X	X+	——	X
PINUS KHASYA	2·4(3·6)5	——	X+	——	38μ	——	——	DITTO	——	1(8)21	X	——	X	X+	——	X
PINUS LONGIFOLIA	1·6(3·9)5·5	——	X—	——	36·3μ	——	——	DITTO	——	1(6)16	——	X—	X	X+	——	X
PINUS MERKUSII	3·8(7)11·4	——	X+	——	41μ	——	——	DITTO	——	1(11)30	X	——	X	X+	——	X
PODOCARPUS NERIIFOLIA	1·6(3·4)5·7	——	X—	X	36μ	——	ABUNDANT; META-TRACHEAL	——	——	1(5)13	X	——	——	——	——	——
TAXUS BACCATA	1·6(2)2·7	X	——	X	21μ	X	——	——	——	1(8)28	——	X—	——	——	——	——
TSUGA BRUNONIANA	1·3(1·4)4·1	——	X—	X	32μ	——	SPARSE, TERMINAL	——	——	1(8)24	——	X—	X	X—	X	——

*₁ NOTE { —— = WANTING; X = PRESENT } { — = RESTRICTED TENDENCY TOWARD MAXIMUM. + = MARKED TENDENCY TOWARD MAXIMUM. } *₂ FUSIFORM RAYS WHEN PRESENT ARE NOT CONSIDERED

[*To face page 83*

evolved at a time (Paleozoic period) when climatic conditions were equitable or nearly so over large areas on the earth. The existing conifers are to be regarded as but a remnant of a vast phyllum which has managed to survive into the present time and their origin as a group under a different type of environment is reflected in the simple structural features which still persist in their wood to-day.

The accompanying table gives in tabular form the minor structural departures which are found in the various indigenous coniferous species. A brief explanation will serve to stress the salient points and to give some insight into the extent of the variation in the different forms.

(*a*) *Tracheids.**

Tracheids make up by far the bulk of the longitudinal cells of coniferous wood and the general shape and alignment exhibited by *chir* holds for all coniferous timbers. They are extremely long cells with tapering ends and are aligned regularly in radial rows which extend through the seasonal ring. (Plates I, II, and III.) The differences which arise in the different tree species are rather those of size, pitting, and thickening.

In column two are enumerated the maximum, average, and minimum lengths of the tracheids of the majority of the conifers native to India. The averages range from 1·4 millimeters for *Tsuga Brunoniana* to as high as 7 millimeters for *Pinus Merkusii*. Tracheid length in by far the greater number of species falls between three and four millimeters and these figures may be considered to be representative for coniferous woods in general.

Columns 3 and 4 are concerned with the bordered pits on the lateral radial walls and the deduction is obvious that the uniseriate condition prevails among Indian species but a tendency is expressed toward a biseriate arrangement through a pairing of pits, especially in broad springwood tracheids. Blue pine, spruce, yew, and the two junipers exhibit pits which are strictly uniseriate. In deodar, *chir*, cypress, hemlock, and *Podocarpus* they are occasionally paired and this tendency is the more enhanced in coarse

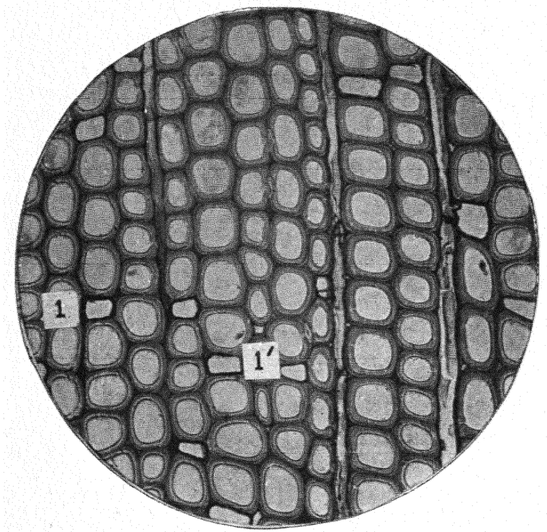
* Parenchyma tracheids occur occasionally as transitional elements abutting on epithelial parenchyma and on longitudinal parenchyma but are too rare to deserve lengthy consideration.

textured woods such as *Pinus Khasya, Pinus Merkusii*, *Abies Pindrow*, and *Larix Griffithii*, where the biseriate condition is a feature of the springwood. The paired arrangement is to be considered as one of the concomitants of coarse texture and always reaches its best expression in the broad tracheids of the springwood.

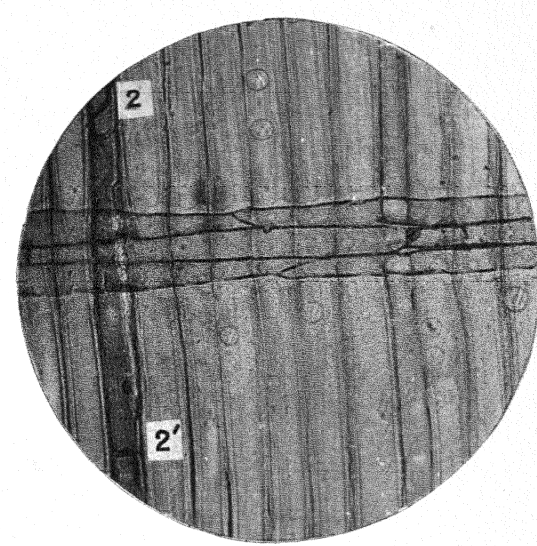
Tangential pitting is present in the wood of all conifers aside from the hard pines (column 5) and attains its maximum development on the tangential walls of the last formed summerwood tracheids. Tracheid walls thicken appreciably in the majority of conifers as the end of the growing season is approached and the diffusion of solutes between cells is as a consequence retarded. Tangential pitting was undoubtedly evolved following seasonal ring formation which in turn was contingent on present day climatic conditions. Its absence from the wood of *Pinus longifolia*, *P. Khasya*, *P. Merkusii*, and *P. Gerardiana* is to be explained in that ray tracheids reach their best development in the hard pine group and ample radial diffusion is assured by the ray structures alone.

Tertiary thickening which takes the form of spiral bands (Figure VIII, 3) extending clockwise on the inner walls of tracheids is a feature of but two Indian coniferous woods, namely yew and spruce (column 6). Such bands represent the final effort on the part of the protoplast to thicken the wall ere cell necrosis took place and are of diagnostic value in the identification of these timbers. Tertiary spirals always feature the woods of *Taxus* and *Torreya* of the *Taxaceæ* and appear as constant features of the Abietineous genus *Pseudotsuga* which produces the Oregon pine of commerce. Their presence in isolated species of *Pinus, Picea* and *Larix* is to be interpreted as sporadic but offering a valuable means of identification.

Tracheids are typical prosenchymatous elements which are the result of a compromise on the part of nature in that they are well adapted to perform both the conductive and mechanical functions. Bordered pits afford a large pit surface without appreciable weakening of the cell wall and the mechanical strength of the element is little weakened thereby. In porous woods to the contrary the tendency is very marked to delegate these separate functions to different types of cells which differ from one another remarkably in their morphological features. Prosenchyma, since it con-



A



B

Photomicrographs by H. P. Brown.

Figure XXV.—Photomicrographs of the wood of ***Podocarpus neriifolia*** in transverse **and** radial section showing longitudinal wood parenchyma.

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sists wholly of dead cells, can have no part in the storage of reserve food.

(*b*) *Longitudinal parenchyma.*

The longitudinal parenchyma of coniferous wood has been designated under various names such as " resin parenchyma " and " wood parenchyma." Both these terms are misleading unless they are understood in a special sense. The appellation of " wood parenchyma " is too comprehensive since rays are a part of the wood and ray parenchyma is not included under this heading. The use of the term " resin parenchyma " to designate these cells may likewise lead to confusion since it implies an intimate relation with resin production. Resin canals are surrounded by parenchyma cells whose function it is to secrete resin and which have been designated collectively as epithelium. But such parenchyma cells arise in a manner apart from true longitudinal parenchyma and are assigned to a different cell category. Confusion is avoided if the cells about resin chambers are designated as epithelial parenchyma, and the remaining parenchymatous cells which course longitudinally in the wood and bear no relation to resin canals as longitudinal wood parenchyma.

Longitudinal wood parenchyma is abundant in the wood of *Podocarpus neriifolia* and is shown in cross and longitudinal sections in Figure XXV, A and B. As seen in transverse section (A—1, 1^1) the cells are generally tabular in form and flattened tangentially, and stand out against the mass of tracheids owing to the fact that their walls are much thinner and stain differently. The walls of longitudinal parenchyma cells remain largely cellulosic in nature though a certain amount of lignification may ensue. If perchance an end wall is included the parenchyma cell then appears darker in color with punctate markings which prove to be simple pits in the terminal wall, viewed in surface aspect.*

The lateral view of the cell is presented in the longitudinal section (B—2, 2^1) and it is seen to be of a general rectangular shape. It follows that a protoplast would be present had the material been collected from the sapwood of a living tree. In the photograph the lumen is occluded by an amorphous deposit which represents either the remains of

*End walls are not included in the figure.

the shrivelled protoplast or a resinous product. Simple pits are features of the terminal and lateral walls of longitudinal parenchyma cells when these attain to any thickness (not visible in the photomicrograph) and where the cell abuts on a tracheid, a semi-bordered pit is formed, a condition which ensues whenever parenchyma is coterminous to prosenchyma.

Reference to the table on page 83 brings out some interesting information as regards the distribution of longitudinal parenchyma in coniferous woods. It is entirely wanting in the Indian pines and *Taxus baccata*. Sparse parenchyma (lacking in some sections) features the woods of the indigenous species of the Abietineous genera *Picea*, *Cedrus*, *Tsuga*, and *Larix*, and furthermore, when present, it is confined to the outer face of the summerwood part of the ring. For reasons which cannot be enumerated in an elementary treatise of this sort, the terminal position is considered to be primitive for elements of this type. In the three cedars on the other hand, namely, cypress and the two junipers, the parenchyma has invaded the annual ring and is always conspicuous in the wood, and the same applies to *Podocarpus neriifolia* where it is exceptionally abundant.

Parenchyma cells remain alive as long as they are a part of the sapwood and it is thought that they play a vital part in the "rise of sap" in trees. In addition they act as storage places for carbohydrate food which is brought to them through the agency of the wood rays. The parenchyma cells of the sapwood, both longitudinal and ray parenchyma, are in intimate association and form an anastomosing cell system which functions as a food reservoir as long as it is included in the alburnum.

(c) *Resin canals.*

Normal resin canals, both longitudinal and radial are present in the secondary wood of but four coniferous genera, namely, *Pinus*, *Picea*, *Larix* and *Pseudotsuga*, the last of which is not represented in India (Plates I, and II). The general features of such cavities have been described for pine (*chir*) and such a longitudinal cavity is depicted at a greater magnification in cross section in Figure XXVI. The central resin cavity is surrounded by several layers of parenchymatous secreting cells (epithelium) which connect the canal to the wood rays that course past it in a radial

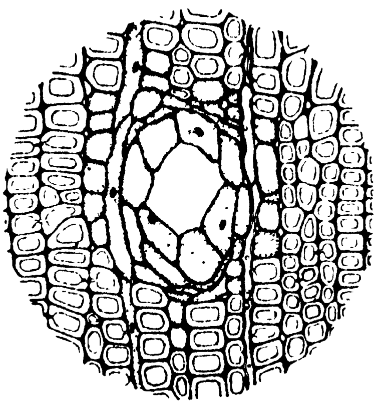

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Figure XXVI.—Schematic drawing illustrating the detailed structure of a longitudinal resin canal of *chir (Pinus longifolia)* as seen in transverse section.

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direction on either side. The epithelial cells are followed (above and below in the figure) by parenchyma tracheids and eventually by tracheids but as these two sorts of elements are identical in transverse section, the one type cannot be separated from the other. Below or above the plane of section the longitudinal canal coalesces with a radially aligned cavity which appears as a "ray" inclusion and exhibits identical features except that it is generally more restricted in size. The longitudinal and radially aligned canals anastomose to form the resiniferous system of the wood.

Resin canals are conspicuous structures in pine wood and attain their maximum size in the hard pine group. The canal orifice can usually be distinguished with the naked eye alone in *Pinus Merkusii*, *P. longifolia*, and *P. Khasya* and readily so with a lens in the soft blue pine (*Pinus excelsa*). The faces of pine boards are usually marked with dark streaks which are traceable to this source and this is a diagnostic feature of no mean value in the identification of pine timber.

Spruce and larch woods in contrast possess small canals which may be easily overlooked on cursory examination at low magnification but are readily observed with the microscope. The canal is restricted in diameter and furthermore, differs from that of pine in that the ephithelial cells are thick walled (Plate II) and in addition often copiously pitted. Such thick walled epithelium, alone serves to distinguish the canals of pine from those of spruce and larch and is a diagnostic feature of first importance.

The remaining genera of Indian conifers do not possess normal resin canals in their secondary wood but traumatic or wound resin cavities may arise on occasion which extend both longitudinally and radially. Such traumatic tissue is of frequent occurrence in deodar (Plate III) and the longitudinal canals are aligned in tangential rows which extend for some distance in the wood, their traumatic nature being indicated by their total absence from many of the rings. Traumatic resin cavities may arise sporadically in *Abies Pindrow* or *Tsuga Brunoniana* and are sometimes features of the wood of exotic conifers (*Sequoia*). Or the number of canals in the newly forming wood may be increased as a result of a wound stimulus. The pines which are repeatedly wounded by tapping for resir

do not yield the maximum flow of resin until the second or third year, a circumstance which is due to the production of an excess number of canals in the wood as a sequel to wounding.

Wound canals like those of the normal type anastomose and form a traumatic resiniferous system. The vertical canals of deodar may be observed to coalesce frequently when longitudinal sections through the wound area are examined and the same may be said to hold true as between the longitudinal and radial cavities.

The significance of resin canals in the secondary wood of certain coniferous trees is probably to be explained in that they are a device to insure protection against wounding and the desiccation of exposed tissues thus resulting. Their sporadic appearance in wood in which they are normally absent is generally considered as a hearkening back to an ancestral condition : reversion in other words.

(*d*) *Wood Rays.*

The anatomical departures in the wood of conifers which are of diagnostic significance are those of the gross dimensions of tracheids (texture), the arrangement of the longitudinal parenchyma, and the sort and arrangement of the cells which enter into the ray structure. Variations in the last are of decided taxonomic value when considered in conjunction with those of the longitudinally aligned elements.

Columns eleven and twelve of the table (page 83), list ray height and ray width in terms of cells as seen in tangential section and since the ray cells of coniferous wood vary little in their dimensions, the figures enumerated in the table may be considered as indicative of the relation which the rays of the various species bear to each other in terms of linear measurement.

The rays of greatest depth are found in deodar and cypress where they average 17 and 13 cells respectively while the other extreme occurs in the two junipers with radial bands but four cells or less in depth. *Juniperus* species are always featured by low rays and the same may be said of the species of *Thuya* and *Chamœcyparis* which belong to the *Cupressineœ* group, but are not represented in India. The remaining Indian species fall between these two extremes. It is only when ray depth becomes significantly low or signi-

ficantly high that it has diagnostic value and then only when considered with other factors.

Those coniferous woods which are featured by resin canals possess occasional rays which are a number of cells thick at the middle but taper to the uniseriate condition above and below the canal orifice. The remaining rays which far preponderate the others in numbers are either strictly uniseriate as viewed tangentially or show more or less of a tendency toward the biseriate condition in their median portion.

Column 12 gives the ray width in cells but takes no account of fusiform rays when these structures accompany the uniseriate type in the wood. It may be seen at a glance that the uniseriate condition is obviously the normal one and is strictly adhered to by the majority of species. A slight tendency toward the biseriate condition is registered in but one pine, *Pinus longifolia*, likewise in *Cedrus Deodara*, *Tsuga Brunoniana*, *Larix Griffithii*, *Cupressus torulosa* and finally in *Taxus baccata*, but this no where comes to complete expression and is generally confined to the median portion of scattered rays.

The uniseriate condition of the wood ray in coniferous wood may be explained purely on physiological grounds. Primary wood is devoid of rays and these structures are developed in secondary wood for the storing of reserve carbohydrate food. But coniferous woods were evolved in prehistoric times when climatic conditions were equitable and there was little demand for storage tissue. In addition, the leaves of modern conifers have assumed the storage function to no small degree during the dormant season. There has been as a consequence no call to develop the massive ray which is a feature of most dicotyledonous woods. Coniferous rays have remained small in size while a new type of wood with conspicuous radial bands, that of dicotyledonous trees, has developed under the stress of modern conditions.

As explained on page 81, coniferous rays present a wholly different aspect when viewed laterally in radial sections. They appear then as muriform structures which sweep across the longitudinal elements at right angles, and are made up of cellular constituents, arranged in tiers. Variation arises through the presence or absence of ray tracheids, their arrangement in the ray structure, and the pitting,

more especially the lateral pitting which is found on the lateral walls of the ray parenchyma cells.

The salient features of the *chir* ray are shown in Figure XXIII. The prosenchymatous dentate ray tracheids are depicted as marginal, separated by a number of rows of ray parenchyma cells with lateral, window-like, semi-bordered pits. Such marginal dentate tracheids are present in the wood of all the hard pines (*P. longifolia*, *P. Khasya*, *P. Merkusii*, and *P. Gerardiana*) and they are generally accompanied by interspersed cells of this type as well. The latter then appear in horizontal, continuous or interrupted rows and replace rows of ray parenchyma in the body of the ray. The interspersed condition of ray tracheids still prevails in the "soft" blue pine (*Pinus excelsa*) and with lessening frequency in *Larix Griffithii* and *Picea Morinda* but dentation has entirely disappeared; the wall presents an even contour when seen laterally and the presence of dentation alone will serve to separate the wood of the "hard" pines from that of the remaining conifers.

In *Tsuga Brunoniana* and *Cedrus Deodara* the ray tracheids are confined strictly to the marginal position and but one row is visible at the edges of the ray. The body of the ray consists wholly of wood parenchyma which is arranged in seried ranks, bounded above and below by a single row of marginal ray tracheids.

Marginal tracheal cells have entirely disappeared from the remaining species of Indian conifers either as normal or traumatic structures. The rays consist of parenchyma cells alone which are copiously pitted on lateral and terminal walls, and less division of labor is expressed in the ray structure. Nor are there structures which are in any way analogous to ray tracheids in the radial bands of dicotyledonous trees. The modern type of ray consists wholly of ray parenchyma.

Figure XXIII will serve likewise to illustrate the two types of pitting as found on the lateral walls of ray parenchyma. Such pits, in as much as they lead from parenchyma to prosenchymatous elements, are of the semi-bordered type but those of pine are characteristic in that the border of the pit is narrowed and a large part of the pit membrane is exposed to view. The result is a window-like structure which reaches its best expression in *Pinus Khasya* and *Pinus Merkusii* but is still obvious in the three remain-

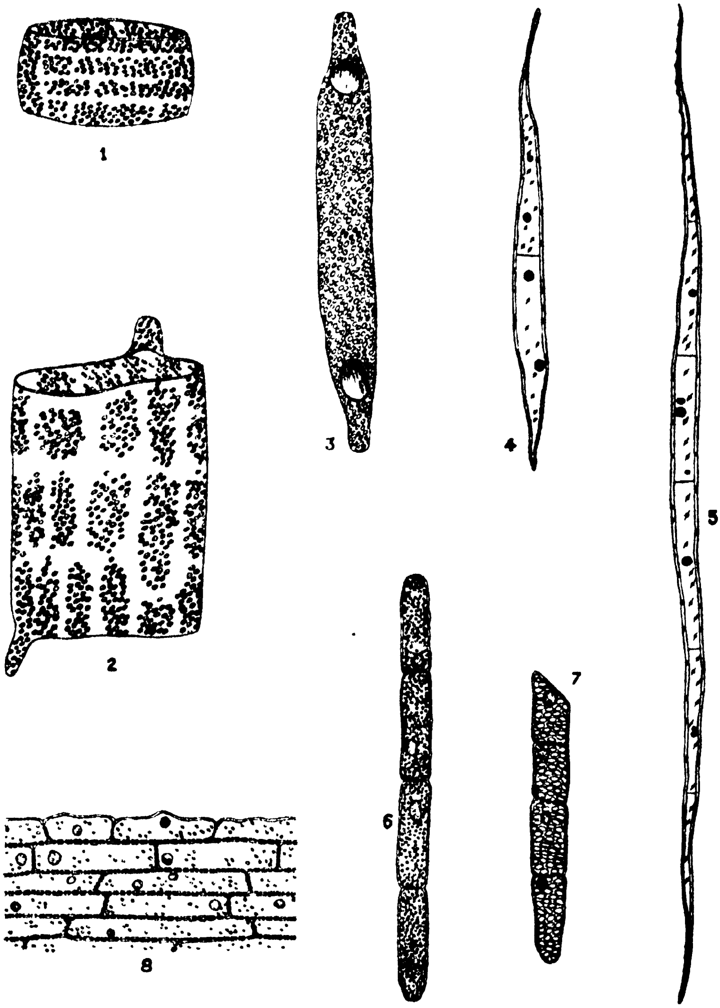

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Figure XXVII.—Elements of teak wood *(Tectona grandis)*, drawn in lateral aspect to a scale of 180 microns = 1 inch. 1, Annular vessel-segment of the spring wood; 2, "Tailed" barrel shaped vessel-segment of the spring-wood; 3, Elongated vessel-segment of the summer-wood; 4, Short, septate, fibre-tracheid; 5, Elongated septate fibre-tracheid; 6, Row of longitudinal parenchyma cells; 7, Same showing different type of pitting; 8, Portion of the upper margin of a wood ray.

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ing species of pine. The lateral pits on the ray parenchyma of the other coniferous genera in contrast are typically semi-bordered with a wide border of the normal type. As viewed in surface view, such pits present all the features of a doubly bordered pit and it is difficult under such circumstances to distinguish ray parenchyma from ray tracheids with their doubly bordered pits, when the latter are present*. The window-like nature of the lateral pitting in the ray parenchyma of pine is a diagnostic feature and serves to distinguish this wood from that of the remaining conifers.

The Elements of Teak Wood.

Teak is a dicotyledonous tree and its wood illustrates admirably the usual features of a ring porous timber. In contrast to the anciently derived conifers which still persist and possess wood of a relatively simple type, the dicotyledons are to be considered as the last stage in evolution though not necessarily the final stage. Dicotyledonous wood possesses highly adaptive features as compared to coniferous wood and is far more complex in structure.

Figure XXVII is a diagrammatic representation of the several elements of teak, drawn to the same scale as those of *chir* (Figure XXI)†, and the most conspicuous feature is the presence of vessel segments (1, 2, 3) of varying size and shape. Such segments when aligned in rows vertically in the tree form the composite elements which are designated as vessels, ducts, or tracheæ and which with rare exception are always present in dicotyledonous wood.

Number 1 is an annular vessel segment from the springwood portion of the seasonal increment. There is little evidence in its mature state that it arose from division of a fusiform initial in the cambium but this is the case. Such segments when stacked one upon another in series make up the large springwood ducts of teak. They are formed at a time when the paramount function of the newly forming wood is that of conduction.

A vessel segment of somewhat different type is shown in number 2, and this might be expected to develop somewhat later in the growing season (further out in the ring). It is fully as wide as number 1 but appears barrel-shaped because

* The pits of ray tracheids are generally somewhat larger in size.
† One inch = 180 microns = 180/25,000 inches.

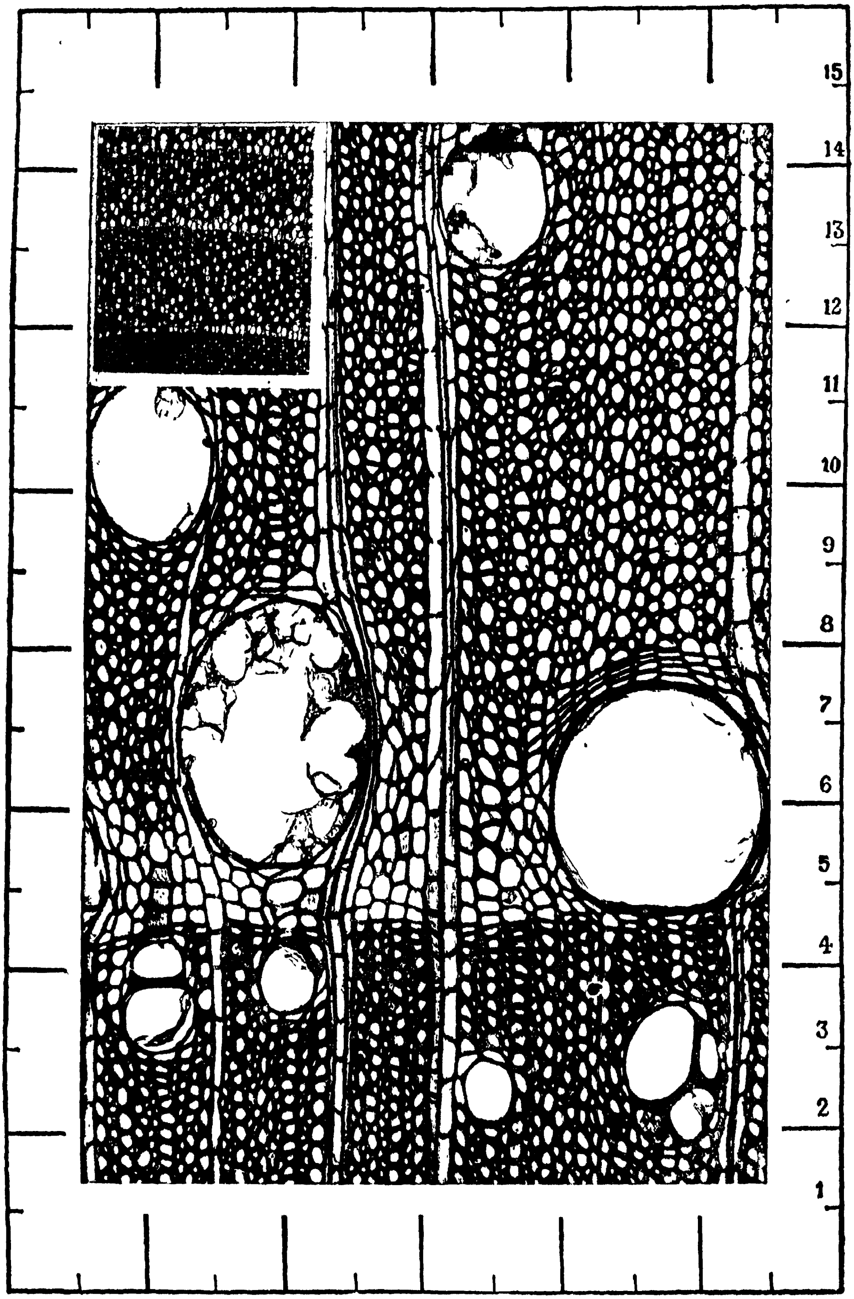
of its greater length; in addition its cellular origin is indicated by short spurs which alternate at either end. Vessel segments of this type are very common in porous wood.

Number 3 depicts the summerwood type of vessel segment which differs from those formed earlier in the season in its greater length, restricted diameter, tapering ends, and oblique pores which connect with similar segments above and below. The hypothesis that units of this sort have descended from fusiform cambial cells (see Figure XIX, B) seems no longer improbable but highly plausible. In fact transition forms between such segments and fibres are not uncommon, especially in certain woods (*Betula*), which indicate clearly their common lineage with typical fibre-cells. Vessel segments obviously belong to the prosenchymatous category as some at least are elongated, and all possess bordered pits and are free of living protoplasts.

The fibrous elements of teak (4) and (5) are designated as septate fibre tracheids and are characterized by tapering ends, delicate septatious at intervals, small bordered pits upon all four walls, and occasional oil globules to which teak owes much of its durability and its scent. Cells of this sort vary considerably in length but in general the shorter units are found in the springwood portion of the wood while those of the long attenuated type are formed in numbers during the middle and latter part of the growing season. As will be explained in the pages which follow, fibre tracheids do not represent the ultimate in the development of the mechanical cell.

The parenchymatous tissue of teak wood consists of longitudinal and ray parenchyma and so much do these two types of cells resemble each other that they cannot always be separated with certainty in macerated material.

Numbers 6 and 7 give the lateral aspect of two rows of longitudinal parenchyma cells, each row having arisen through the periclinal division of a fusiform initial in the cambium. Following this, septa were formed as a post-cambial development, the walls thickened somewhat but copious simple pits were left to insure communication with neighbouring elements, either parenchyma or prosenchyma. That the type of simple pitting varies somewhat is obvious from a comparison of the two rows. The oil globules which are found in all the elements of teak again show to advantage. Such parenchyma cells in addition retain living pro-



Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

Figure XXVIII.—Photomicrograph illustrating the structure of teak wood (*Tectona grandis*) as seen in transverse section.

[To face page 93].

toplasts as long as they are a part of the sapwood but these have been purposely omitted in the drawing.

A radial view of a portion of a wood ray is shown in number 8. The ray parenchyma cells present the same general details of shape, pitting, and oil content as those of the longitudinal parenchyma but differ in their horizontal alignment and muriform grouping. As was pointed out previously, the rays of dicotyledonous woods consist wholly of parenchyma; ray tracheids are never present.

Microscopical Structure of Teak Wood.

The ring porous nature of teak wood is evident from Figure XXVIII. The early portion of each ring is conspicuous owing to the large vessels that are imbedded in masses of smaller thin walled cells between the wood rays and form a zone one or two pores wide which stands out sharply against the dense summerwood of the preceding year*. By far the majority of the smaller cells belong to the parenchymatous category. The longitudinal parenchyma of teak wood is of the paratracheal type (about the vessels) but in the spring wood immediately coterminous to the growth ring of the preceding year occupies the bulk of the area between pores and rays. Some of the springwood vessels are solitary and are connected laterally to the wood rays by parenchyma. Others abut either tangentially or radially on tubular elements of like nature with which they are in communication by bordered pits, or more rarely three or four ducts are grouped together. An additional feature is the presence of tyloses which partially occlude the vessel orifices here and there and plainly show their parietal extraction since they appear as cyst-like structures which jut into the vessel cavity and if perchance the plane of section is median to them, may be seen to be attached to the wall itself.

The springwood zone of teak is produced at a time when the paramount function of the newly forming wood is that of conduction. The large spring wood pores which are devoid of tyloses at this period facilitate the rapid movement of water and solutes to the apices of twigs where elongation is progressing vigorously. Appreciable amounts

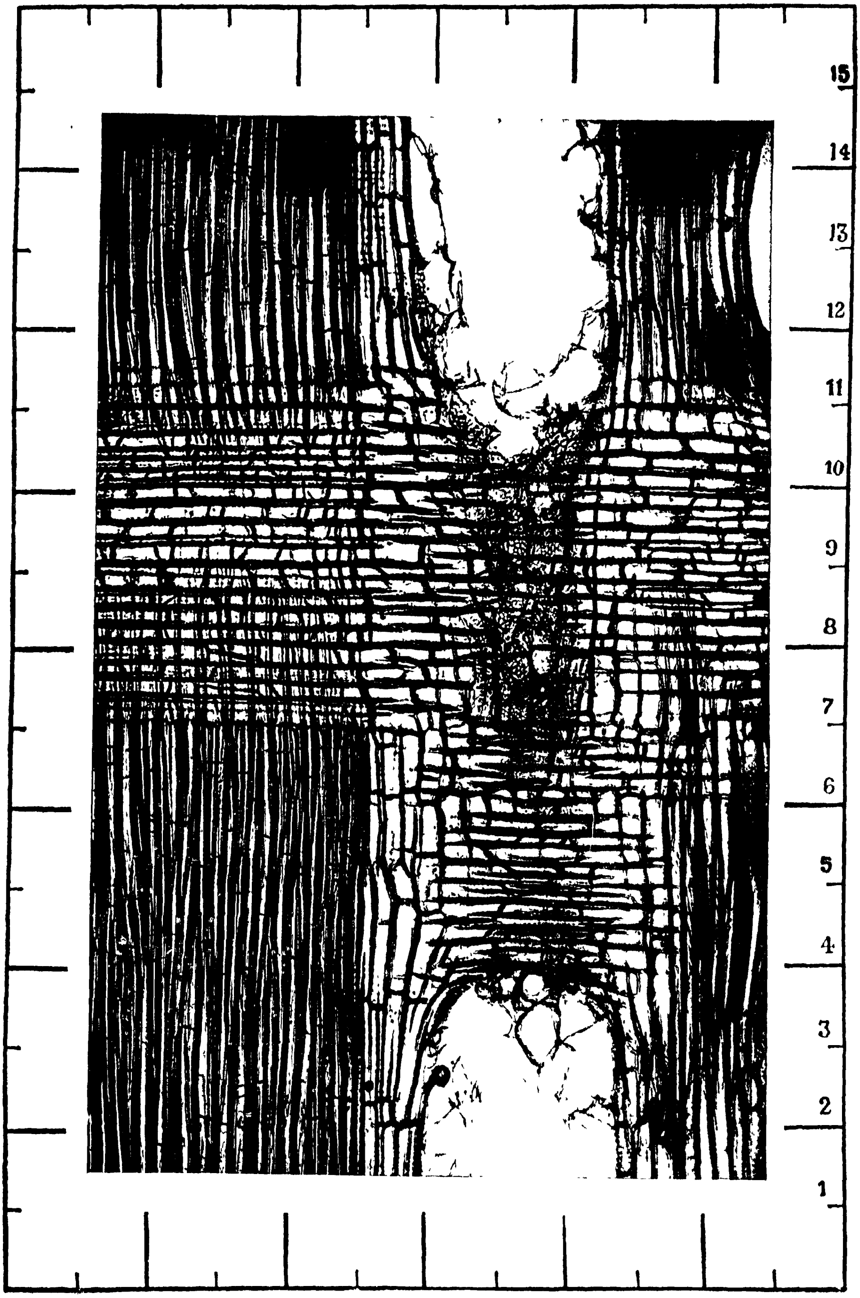
* The radial alignment of longitudinal elements which is a feature of all coniferous woods is not as obvious in porous wood (teak).

of the carbohydrate food necessary for growth are dumped into the ascending sap stream from the paratracheal parenchyma immediately surrounding the vessels and the tree has found it to advantage to develop this last tissue in quantity to accompany the springwood ducts, even though it must needs be done at the expense of the mechanical tissue. The longitudinal tissue of the vernal wood as a result consists largely of wide lumened vessels and parenchyma while fibrous cells are greatly restricted in number.

As the growing season progresses, length growth becomes more and more sluggish and finally ceases altogether. The demand for the rapid movement of solutes to the apical growing points wanes while thickening is still in progress. More and more attention is devoted to the production of mechanical (fibrous) tissue in the summerwood zone. The vessels become greatly restricted in diameter and concomitant with this is a reduction in the paratracheal parenchyma which serves to conduct and store carbohydrate food; it is now confined to the immediate vicinity of the pores as a parietal layer. Fibre tracheids meanwhile appear in ever increasing numbers and their walls grow thicker as the end of the season approaches. The mechanical function is now in the ascendant and this condition continues until the cambium passes into the dormant condition at the end of the season. Year by year this seasonal cycle is repeated and a succession of zones is formed, each concentric with the one preceding.

Reference again to Figure XXVIII brings out another feature which characterizes many of the dicotyledonous woods, namely, the multiseriate type of wood ray which is in striking contrast to the uniseriate radial bands of coniferous timbers. The rays which happen to be included in the photograph are from one to three cells in width and this might lead to the erroneous conclusion that they vary from the one to the three seriate condition in teak wood. This illusion arises in that they are cut at different heights and the one-rowed bands represent the uniseriate margins of rays which are several seriate through their median portion.

The radial aspect of teak wood at high magnification is shown in Figure XXIX at the junction of two seasonal zones. The dense tissue at the left consists of septate fibre tracheids which were formed at the close of a growing sea-



Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

Figure XXIX.—Photomicrograph illustrating the structure of teak wood (*Tectona grandis*) as seen in radial section.

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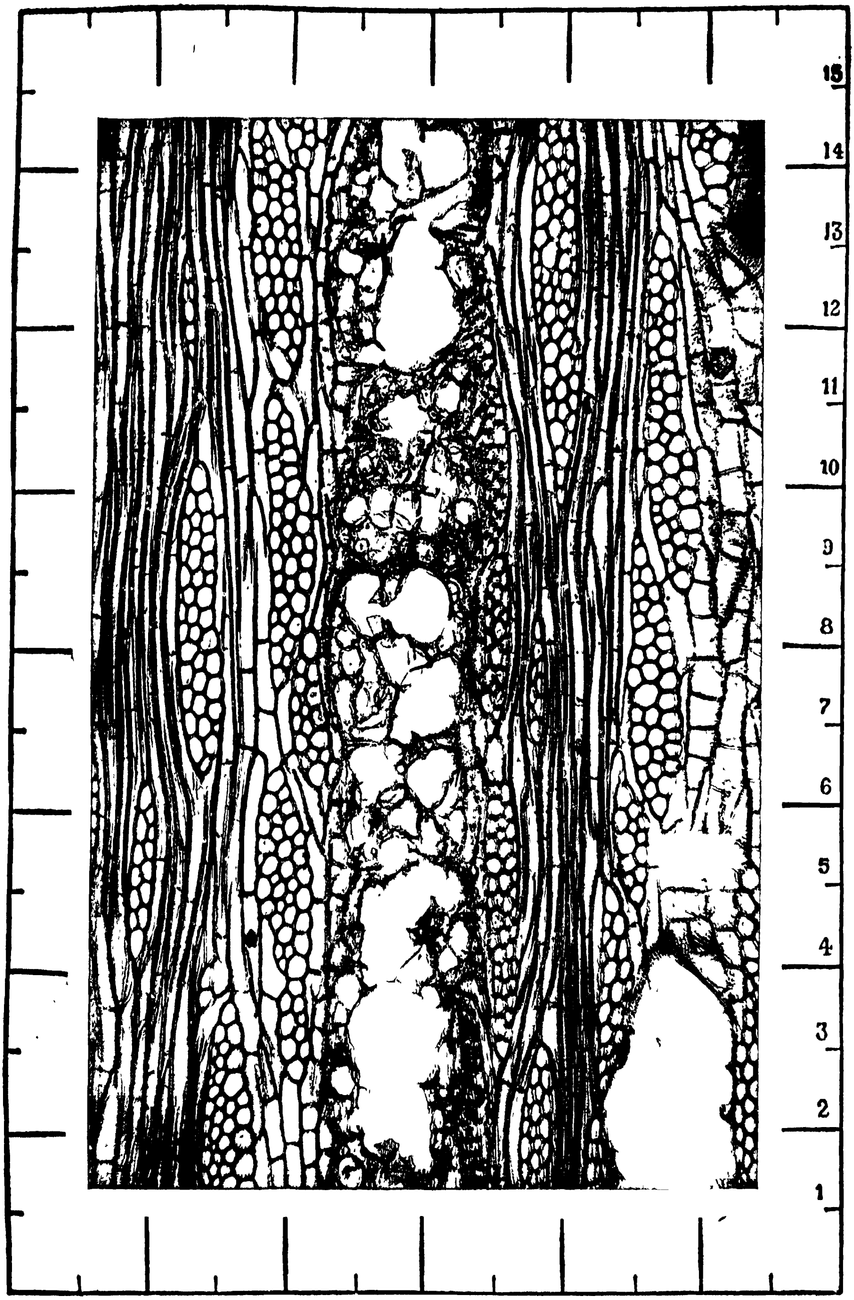

Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

Figure XXX.—Photomicrograph illustrating the structure of teak wood (*Tectona grandis*) as seen in tangential section.

[To face page 95.]

son and this is followed at the right by the springwood zone of the following ring. The latter consists of a large vessel, cut longitudinally, with its sparse tyloses and enveloping parenchyma, the latter in turn giving place toward the right margin to the rather wide lumened fibre tracheids of the vernal wood. The median portion of the photograph is occupied by a multiseriate wood ray which sweeps across from right to left and seemingly interrupts the continuity of the vessel, a fact which serves to stress the point that the course of tracheæ through the wood is by no means a straight line.

Figure XXX depicts the microscopy of the tangential face of teak wood. Transverse sections of the wood rays are shown to advantage and they now appear as biconvex structures which are from two to four cells thick through their median portion but uniseriate on their upper and lower margins. This obviously explains why the width of these radial bands varies as seen in cross sections of the wood. A vessel occupies the central position in the photograph and is largely occluded with tyloses, but the various vessel segments can be traced without difficulty through its median portion. A second element of this type is evident in the lower right hand corner but this runs out of the plane of section and is replaced above by parenchymatous tissue which always occupies a paratracheal position in teak wood. That the fusiform shape of embryonic cambial cells is registered in the wood is obvious from the fact that the longitudinal parenchyma cells are borne in short rows which terminate in gable-shaped ends. Septate fibre tracheids course vertically in the wood which present the same appearance as in the radial section. It follows that they arise from the same cambial origin as the vessel segments and parenchyma rows but are much narrower, owing to the fact that they exhibit pronounced sliding growth* and, as they push past one another, must of necessity become restricted in tangential diameter.

Comparison of Chir and Teak Woods.

The several photographs of teak wood which have just been described were shown at the same magnification as the photographs and drawing of *chir* (Figures XXII, XXIII, and XXIV). As a matter of comparison the anatomical

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*See page 77.

features of these two woods are summed up briefly in tabular form below.

Scientific Name.	Longitudinal Elements.	Radial Elements.	
Chir (*Pinus longifolia*)	(*a*) tracheids (*b*) parenchyma-tracheids (*c*) epithelial parenchyma (*d*) (longitudinal resin canals = intercellular spaces).	(*a*) ray tracheids (*b*) ray parenchyma } Uniseriate rays (*c*) epithelial parenchyma (*d*) radial resin canals = intercellular spaces	Fusiform rays.
Teak (*Tectona grandis*)	(*a*) vessel segments (*b*) longitudinal wood parenchyma (*c*) septate fibre-tracheids	(*a*) ray parenchyma . .	Multi-seriate rays.

1. The composite elements known as vessels, ducts, or tracheæ are lacking from *chir* wood; teak wood possesses vessels.

2. The longitudinal elements of *chir* wood consist largely of tracheids which exhibit striking radial alignment, possess conspicuous border pits on their radial walls, and apparently perform both the conductive and the mechanical function equally well. Tracheids are wanting in teak wood but are replaced by vessel segments and septate fibre tracheids without striking radial alignment and with small inconspicuous pits on all longitudinal walls. The vessels are designed largely for conduction while in fibre tracheids the mechanical function is chiefly paramount. The tracheids of *chir* (average 4 mm.) are much longer than the septate fibre tracheids of teak (average 1·2 mm.).

3. True longitudinal parenchyma is wanting in *chir* as the epithelial parenchyma about the resin canals is of different extraction. Longitudinal parenchyma is abundant in teak and occupies the paratracheal position.

4. *Chir* possesses resin canals which are not elements in the strict sense but intercellular spaces. Resin canals are wanting in teak.

5. The wood rays of *chir* are uniseriate except where they include the radial resin canals; in such cases they become fusiform and several are seriate through the median portion. The wood rays of teak are biconvex in transverse section and from 2—4 seriate.

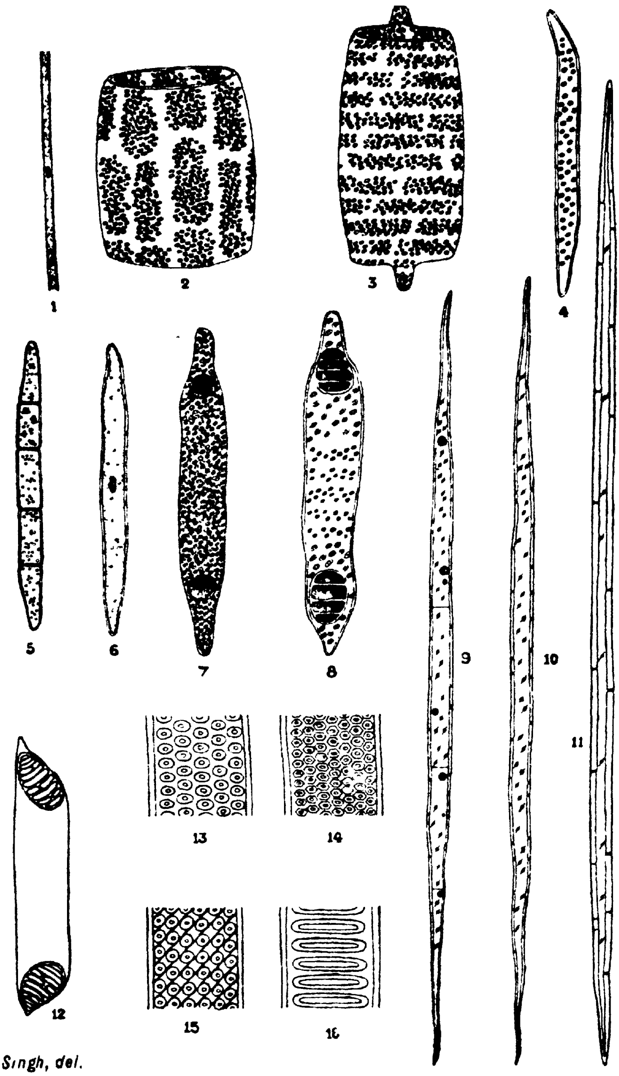

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Figure XXXI.—The longitudinal elements of dicotyledonous wood in lateral radial aspect (aside from 12). **1, Cambial** initial ; 2, Vessel-segment from the springwood ; 3, Vessel-segment from the springwood with "tailed ends"; 4, Tracheid ; 5, Row of longitudinal parenchyma cells ; 6, Substitute fibre ; 7, Elongated vessel-segment with simple perforations ; 8, Elongated vessel-segment with scalariform perforations ; 9, Septate fibre-tracheid ; 10, Fibre-tracheid : 11, Libriform fibre ; 12, Vessel-segment with scalariform perforations, oblique view ; 13, Portion of a vessel-wall with rounded bordered pits ; 14, Portion of a vessel-wall with crowded hexagonal bordered pits ; 15, Portion of a vessel-wall with tertiary spirals and bordered pits ; 16, Portion of a vessel-wall with scalariform bordered pits.

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6. *Chir* wood is of ancient origin and of comparatively simple structure. Teak wood in contrast is of modern origin and exhibits many evidences (vessels, large rays, etc.), of high specialisation and of adaptation to present day environment.

Resumé of the Microscopical Features of Indian Dicotyledonous Woods.

A survey of the microscopical features of wood is of necessity founded on the fact that it consists of different sorts of cellular elements. The study of dicotyledonous timbers serves to stress the point that while the number of cell types is restricted, these are arranged in a bewildering array of permutations that are responsible for the many timbers of commerce. The whole gamut of structural variation results not from many kinds of cells but rather from the sorting of a comparatively small number of cell forms.

While a critical study of teak wood serves to illustrate the general anatomical features of a porous timber, it affords no conception of the morphological deviations which are present in dicotyledonous woods and which play such an important role in their identification and utilisation. The pages which follow are devoted to a summary of the most striking of these structural departures and should convey some idea of the variations which may be anticipated.

Figure XXXI gives the morphological range of elements which is to be found in porous wood but it must be understood that it does not represent the dimensional range*. Number 1 is not a wood element but a cambial cell as seen in radial view and the other cell types are to be considered as having arisen from this through the formation of daughter cells which in maturation elongated, widened, and thickened in various ways as they were incorporated into the wood. All are shown in radial view aside from number 12.

(*a*) *Vessels* (*ducts, tracheæ*).

The various types of vessel segments are depicted (Figure XXXI) under numbers 2, 3, 7, 8 and 12 respectively and deserve but brief description. The barrel-shaped segment

* The scale is the same as that used in the figures of chir (Figure XXI) and teak (Figure XXVII) elements, that is 180 microns or 180/25,000 inch = 1 inch.

(2) is characterized by terminal orbicular perforations and small bordered pits, the latter arranged in rectangular groups which indicate where the vessel was in contact with rows of longitudinal parenchyma cells. Terminal spurs are wanting and it is evident that a unit of this sort must have arisen through a widening of a cambial embryonic cell accompanied at the same time by a slight reduction in its length and the disappearance of the terminal walls. Annular or barrel-shaped vessel segments with simple terminal perforations at right angles to the longitudinal walls, are features of the wood of those dicotyledons which are considered to be of most modern extraction (*Lagerstrœmia, Fraxinus*, *Tectona*, *Quercus*, etc.). As was pointed out on page 91, they are a constant feature of the springwood of teak but gradually give place in the summerwood to vessels of type 7.

The segment of type 3 differs from the preceding in its greater length, terminal spurs which are indicative of its cellular organ in the cambium, and the manner in which its pits are grouped on the wall toward the observer. As the mature segment was evolved from its embryonic initial, appreciable widening took place as in number 2, but this was accompanied by some elongation. The grouping and nature of the pits is to be explained in that a wood ray swept across the face of the vessel and, while the pits appear bordered, they are in reality of the semi-bordered type. At the same time the increase in the angle of the pit orifices is but an expression of the change in the spiral alignment of the ultra-microscopic particles which make up the secondary layers of cell walls.

Vessel segments of "tailed" form are very frequent among dicotyledonous woods, either diffused throughout the seasonal zone or confined largely to the springwood portion. They are representative of a high (modern) type of evolution in the vessel owing to their simple horizontal perforations but still retain some evidence of their cellular origin from the embryonic initials arising in the cambium. It is apparent that they are intermediate in shape between the extremes figured under 2, 7, 8 and 12, respectively.

The primitive vessel was undoubtedly made up of segments of the kinds figured under 7, 8, and 12. In com-

parison to those described above, these are seen to be comparatively narrow units with oblique pits and terminal perforations which are either of the simple (7) or scalariform (8, 12) type. The latter are considered to be the more primitive and to have arisen first from fusiform cells through a partial breaking down of oblique terminal walls to form a lattice. Eventually the bars disappeared in those forms which continued to advance and a circular simple perforation was produced which still, however, retained its position on an oblique terminal wall (7). If our theory of the evolution of the vessel is tenable, the sequence is as follows:—

tracheids
↓
elongated vessel segments with latticed perforations on oblique end walls.
↓
elongated vessel segments with simple circular perforations on oblique end walls.
↓
tubular vessel segments with tailed ends and simple circular perforations which are horizontal or nearly so.
↓
barrel- shaped or annular vessel segments with simple circular perforations which are horizontal.

Vessel segments with simple perforations are altogether too common in dicotyledonous wood to be of taxonomic significance and are to be considered as the usual type in porous timbers. The latticed form to the contrary is relatively rare and the presence of scalariform terminal perforations is often sufficient alone, to separate woods which may otherwise appear quite similar to the novice. The classic example in the north temperate zone is that of birch and maple, the former being characterized by latticed vessel perforations in contrast to the simple circular openings of maple. Scalariform vessel segments have been observed incidentally in the following Indian genera but the list will undoubtedly become somewhat amplified on further study. It should be noted in this connection that when present "barred" perforations are usually of generic significance but in some instances at least are confined to

individual species within a genus. They are restricted wholly to the woods of the diffuse porous type.

TABLE.

Genera with Latticed Vessel Perforations.

Dilleniaceæ.
  Dillenia.
Magnoliaceæ.
  Magnolia.
  Manglietia.
  Michelia.
Ternströemiaceæ.
  Camelia.
  Gordonia.
  Saurauja.
  Schima.
Aquifoliaceæ.
  Ilex.
Celastraceæ.
  Kurrimia.
Sapindaceæ.
  Turpinia.
Staphyleaceæ.
  Staphylea.
Sabiaceæ.
  Meliosma.
Saxifragaceæ.
  Deutzia.
  Hydrangea.
  Itea.
Hamamelidaceæ.
  Altingia.
  Bucklandia.
  Parrotia.
Rhizophoraceæ.
  Bruguiera.
  Rhizophora.
Araliaceæ.
  Heptapleurum.
  Heteropanax.
Cornaceæ.
  Aucuba.
  Cornus.
  Mastixia.
  Nyssa.
  Torricellia.
Caprifoliaceæ.
  Viburnum.
Ericaceæ.
  Gaultheria.
  Pieris.
  Rhododendron.
Styraceæ.
  Styrax.
  Symplocos.
Myristicaceæ.
  Myristica.
Euphorbiaceæ.
  Buxus.
  Daphniphyllum.
Fagaceæ.
  Alnus.
  Betula.

It is clear from Figure XXXI that vessel segments are typically prosenchymatous cells since protoplasts are wanting and bordered pits are generally present on those lateral walls that are in contact with other vessels or with tracheids. As is to be anticipated, however, in such a large and heterogeneous group as the dicotyledons there are many minor modifications in the type of pits or in their arrangement which are peculiar to the vessels of certain woods and which are therefore of taxonomic significance.

Numbers 13 to 16 inclusive portray four types of pitting which are not uncommon on lateral vessel walls. The first, in which the numerous pits are clearly separated from one another represents perhaps the more usual arrangement. The vessel segments of *Gmelina arborea* (Plate XIV) are typical exponents of this sort of grouping but many other examples could be selected from among Indian woods.

The crowded condition of 14 in comparison results in hexagonal pits which are aligned in spirals across the face

of the vessel. This obviously provides for more pits per unit of area, and hence greater diffusion is insured through the vessel wall. The vessels of many of the *Terminalias* exhibit hexagonal pits and this type attains complete expression in the vessels of the wood of *Tectona Hamiltoniana* (Plate XII).

Scalariform pitting (No. 15, Figure XXXI) is more rare than that of the two types described in the preceding paragraphs but when present, is too striking to be overlooked. It is generally found in vessel segments with latticed perforations (but does not of necessity always accompany these) and evidently arises from the fusion of lateral bordered pits of the usual sort. In fact transitional stages are frequently to be found on the lateral wall of a vessel segment, which are indicative beyond doubt of the mode of origin of pits of this type. Scalariform pitting is a feature of such woods as *Rhizophora* (Plate XI), *Michelia*, and *Magnolia*.

The last type, which is figured in 16, is characterized by the presence of spiral bands that sweep obliquely across the vessel wall on the inside and are in reality tertiary spirals which were formed by the protoplast in the final stage of thickening. Such bands obviously avoid pit orifices but cross pit borders in many places and are restricted to those inner walls which are in contact with other vessels or with tracheids. Manifestly they may be confined to the tangential walls of the vessel alone or extend completely around the wall, depending on the nature of the other elements which perchance abut upon the vessel. They are clearly visible in the vessel segment of *Acacia leucophloea*, which is to be seen in the upper right hand corner of Plate XV.

In summing up it is well to note that while bordered pits are typical of the walls of vessels, they are by no means constant features. Where the vessel is surrounded completely by mechanical elements of the extreme type (libriform fibres) the walls may be entirely devoid of pitting. Or simple pits exceptionally may lead from vessel segments to wood ray cells and offer a taxonomic character of some importance, as in the willow (*Salicaceæ*) and walnut (*Juglandaceæ*) families.

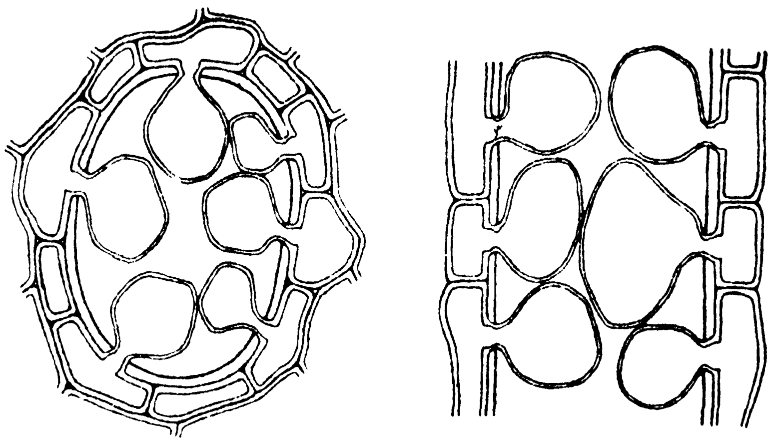
The size of pits likewise varies remarkably in the different woods and is often of diagnostic value in an intensive study. Frequently this character holds for all or the majority of the woods of a family. For example the willows and poplars possess large pits on their vessel segments and the same is true of the majority of the Lauraceous woods, the *Acacias*, etc. The other extreme is found in the extremely fine pits of such timbers as *Pentace burmanica*, *Chloroxylon Swietenia*, *Diospyros Melanoxylon*, and *Betula utilis* where, even at high magnification, they present a punctate appearance.

(*b*) *Tyloses.*

Tyloses are abundant in many woods and attain their best development in vessel cavities but they are by no means confined to them. Resin canals are sometimes occluded by these structures and they are not infrequent in the mechanical cells of certain timbers (*Aesculus*, *Altingia*).

The parietal origin of tyloses was mentioned in the description of teak wood on page 93, and Figure XXXII is a diagrammatic representation of the manner in which they arise. From the drawing it is evident that they take their origin from the membranes of pits which lead from the vessel cavity to neighbouring parenchymatous cells. The pit membranes become greatly enlarged and arch out into the vessel cavity. At the same time, some of the protoplasm and occasionally nuclei, pass through the pit canal into the forming tumor-like cyst which usually continues to enlarge until it comes in contact with other cysts projecting from the vessel wall at different places. Eventually, if the process is continued, the pore is completely occluded and, as has been explained previously, this has a considerable bearing on the durability of the wood.

Tylosic formation is generally instituted as the woody tissue passes over into heartwood and the majority of the cyst-like structures arise from the parenchyma of wood rays. This is possibly to be explained in that no provision is made in the cambium, so far as space is concerned, for the enlarged cells which we know as vessel segments. As these increase to their maximum size, they crowd the neighbouring elements including wood rays to the right and left (tangentially). Tension results in the walls of



A   B

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Figure XXXII.—" A " depicts a transverse section of a duct showing tyloses, while " B " shows a duct in longitudinal section.

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neighbouring parenchyma cells which possibly reaches expression in the formation of tyloses as the tissue passes over into heartwood.

The extent of tylosic formation varies considerably in different woods. For example, sparse tyloses are a feature of the wood of the *Calophyllums*, of *Duabanga sonneratioides*, and the various species of *Dipterocarpus*. Railway sleepers of the last respond readily to the creosote treatment because the pores are open for the most part. Teak wood is very variable in the tylosic content of its vessels and too much value should not be placed on this character in its identification. The extreme condition is found in the timbers of *Lagerstrœmia*, in some of the *Shoreas*, and in such woods as *Careya arborea*, *Berrya Ammonilla*, and *Bischofia javanica*, where the vessels of the heartwood are generally stopped completely.

In by far the majority of cases, tyloses remain comparatively thin walled and are entirely devoid of pits (*Lagerstrœmias*). When seen *en masse* their walls reflect the light strongly and may appear more or less iridescent; in fact the lustre of some woods is undoubtedly enhanced to some extent by their presence. In other woods in comparison they become sclerosed to a varying degree and are then often copiously pitted (*Terminalia paniculata*), a feature which is of some value in identification. The presence of numerous tyloses in vessel cavities is always an indication of the durability of a timber.

(c) *Tracheids.*

The second and final type of tracheal element in porous wood is depicted in number 4, Figure XXXI. It is known under the same appellation as the fibrous cells of coniferous wood, namely, as a tracheid but there the similarity ends. The tracheids of dicotyledonous timbers are usually comparatively short (approximately one half millimeter or less) and are always, when present, closely associated with and generally applied to vessel segments; in fact, so close is this association that the average length of the vessel segments is usually a safe measure of the long dimension of the tracheids which accompany them.

As is indicated in the figure, the tracheids of porous wood arise as individuals from embryonic cells which

lengthen but little following their origin in the cambium and acquire tapering blunt ends and numerous small bordered pits on all longitudinal walls. They differ in this respect from the similarly named elements of coniferous wood which show a strong predilection to confine their pits to radial walls, particularly in the spring wood. This feature, coupled with their restricted longitudinal dimension and small inconspicuous pits, is sufficient to distinguish dicotyledonous tracheids from the coniferous cells which they resemble only in name.

Tracheids are not constant features of dicotyledonous wood, a condition which is well illustrated by teak, in which they are totally wanting and are replaced by septate fibre tracheids. As has been stated above, when tracheids are present, they are always associated with vessels and immediately coterminous to them, and have as their primary function the conduction of water and solutes, acting in an accessory capacity to these composite elements. Moreover, in those ring porous woods in which they are found, they often exhibit a strong tendency toward restriction to the springwood portion of the ring. For example, the longitudinal elements produced during the first part of the season in oak wood consist of vessels, tracheids, and parenchyma, while in the outer part of the ring the tracheids give place to the more mechanical fibre tracheids or libriform fibres. In no case do tracheids form a conspicuous part of the secondary wood of dicotyledonous trees, except in a few freak types where they alone make up all or the bulk of the longitudinal tissue of the xylem (*Drimys*, *Trochodendron*).

(*d*) *Fibres.*

Numbers 9, 10, and 11 of Figure XXXI are to be regarded as prosenchymatous-mechanical rather than prosenchymatous-tracheal in nature; in other words they are designed largely to perform the mechanical function as compared to the conductive function which is paramount in dicotyledonous vessels and tracheids, and this is evidenced by their greater length, restricted pit number, and thicker walls in the extreme form (11). Numbers 9 and 10 are identical except for the delicate septations of the former. They are designated as septate fibre tracheids and fibre tracheids respectively and are examples of a type

of cell intermediate between the tracheid (4) and the extreme form (11). Fibre tracheids make up the whole of the mechanical tissue of some woods (teak); in other cases they are accompanied by cells of the extreme mechanical type as well.

The final effort on the part of nature in the production of a mechanical element is that of the libriform fibre shown in 11; it is a thick-walled, long attenuate cell with restricted lumen and extremely small pits which are bordered or simple by reduction. Such cells possess great strength owing to their thick walls and play no real part in the conduction of water and solutes. As a matter of fact the mechanical function has become dominant in them to such an extent as to preclude their functioning in any other way.

The presence of large numbers of libriform fibres in a wood is indicative of high specific gravity and great strength. Among Indian timbers they attain their best development in such woods as *Xylia dolabriformis*, *Mimusops Elengi*, *Mesua ferrea*, and *Olea ferruginea*, and the strength of these timbers is traceable in no small part to them.

(*e*) *Longitudinal wood parenchyma.*

The longitudinal parenchyma of porous wood is chiefly concerned in the conduction and storage of carbohydrates. Trees which are dormant for a portion of the year usually store up quantities of reserve food for the growing period the following year when elongation is progressing rapidly. Or in other instances a reserve supply is gradually built up pending a time of seed formation. In either case the wood parenchyma of the sapwood, both ray and longitudinal, acts as a reservoir for food which becomes available subsequently as needed.

The longitudinal parenchyma cells in the majority of dicotyledonous woods are borne in short rows of a half dozen or less (Figure XXXI, No. 5), which are traceable to the post cambial modification of an elongated emryonic cell as it is left behind by the growing layer. It is evident from the figure that such a row arises through the widening of the parent cell and the formation of cross walls at intervals, accompanied at the same time by a

certain amount of wall thickening and the production of simple pits.*

Longitudinal parenchyma cells in contrast to the prosenchymatous vessel segments, tracheids, and fibres, retain their protoplasts long after maturation, in fact so long as they are a part of the sapwood, and to this feature is traceable† their capacity for storage.‡ They either abut directly on ray parenchyma or are in communication through elements of a similar nature with the wood rays, forming with them the parenchymatous system of the wood.

The pitting of parenchyma cells is invariably of the simple type though, as is to be anticipated, minor modifications develop which have little or no diagnostic significance. Frequently the pits are scattered over the wall (Figure XXXI, No. 5), and form punctate fields as seen in surface view. In other cases, more especially where vertical parenchyma abuts on wood rays, a number of pits are grouped together and appear to be framed with a faint halo because the pit field is set in a depression in the wall. Or more rarely the boundary of the pit enlarges appreciably and where the pits are numerous, a reticulate appearance is given to the cell wall (Figure XXVII, No. 7), the meshes of which bespeak of pit membranes separated by narrow strips which belong to the secondary wall.

The distribution of longitudinal parenchyma has already been described at length under the macroscopic features of wood (page 53). It undeniably possesses important phylogenetic and taxonomic significance in a study of wood anatomy and undoubtedly arose in response to a demand for storage tissue as a sequel to the appearance of seasons in pre-historic times, the last contingent upon earth cooling. The plates at the back of the book illustrate (see explanation accompanying each plate) the several types of parenchyma arrangement.

(f) *Substitute fibres.*

The final type of longitudinal element in wood is the so-called substitute fibre (Figure XXXI, No. 6), which par-

*In some dicotyledonous woods (*Tilia*) it is not possible to trace the rows of longitudinal parenchyma to elongated cambial initials.

† Dead cells cannot act as food reservoirs.

‡ Wood parenchyma cells, both longitudinal and radial, may on occasion become repositories for crystals (usually of calcium oxalate) and they are then designated idioblasts.

takes of the nature of prosenchyma in the matter of shape but belongs to the parenchymatous category. In outline such units resemble tracheids (No. 4) but differ in the fact that their protoplasts remain alive and continue to function as long as these cells are included in the sapwood. Their affinity to true longitudinal parenchyma is the more evident through the presence of numerous simple pits which dot all the longitudinal walls.

Substitute fibres are comparatively rare in woody plants (*Berberis*) but are frequent in the xylem of the vascular strands of many of the dicotyledonous herbs. They represent a convenient arrangement in that both the mechanical and storage functions are relegated to the same cell, a condition which is of advantage in the slender, ephemeral stems of herbs and vines.

(g) *Wood Rays.*

Mention has already been made of the significance and gross features of wood rays and the intimate structure of the radial bands of teak have been described in some detail (pages 91 to 95 inclusive), but it yet remains to point out the anatomical features which are present in other porous woods which are decipherable only at high magnification.

By far the majority of the dicotyledonous woods are featured by diffused rays (see page 47) which may be of the uniseriate or multiseriate type. The former condition reaches typical development in such woods as *Diospyros Ebenum and D. Melanoxylon*, *Mesua ferrea*, *Aesculus indica*, *Terminalia bialata* and *Oliveri*, *Pterocarpus santalinus* and *P. dalbergioides*, *Gluta travancorica* (Plate X), and a host of other timbers in which the radial bands are scarcely visible with a pocket lens. The other extreme of the diffuse type is represented by the broad rays of *Carallia integerrima* and the somewhat less conspicuous radial bands of the various species of *Dipterocarpus* (Plate VIII), *Cordia* (Plate IX), and *Dillenia*. All gradations between the uniseriate and the extreme broad ray types are to be found among Indian timbers which, when considered in conjunc-

tion with the other structural features, are of diagnostic value to varying degree.*

As is to be expected the depth of rays fluctuates widely in indigenous timbers and is sometimes a valuable aid in identification. The storied rays of *Pterocarpus Marsupium* figured in Plate XIII are of the shallow sort and the same applies to the other species of *Pterocarpus* native to India.† Rays of medium depth are illustrated by the woods of *Gluta travancorica* (Plate X), *Tectona Hamiltoniana* (Plate XII), *Gmelina arborea* (Plate XIV), and *Acacia leucophlœa* (Plate XV). Mangrove wood has exceptionally deep rays (Plate XI) and a similar condition prevails in *Bombax malabaricum*, the *Dillenia* and *Dipterocarp* timbers, *Careya arborea*, *Soymida febrifuga*, etc.

In this connection it is well to note that ray depth is a more conservative feature than ray width and therefore possesses greater diagnostic value. The latter may fluctuate widely in wood taken from different trees or from different places in the same individual while ray depth of a given sort is often a character constant to all the species of a genus (*Dipterocarpus*).

A further feature of wood rays which has been used with varying success in timber identification is evident only in radial sections where the ray is seen in lateral aspect. When the cells which constitute the muriform parenchyma‡ of the ray structure are all similar or nearly so in size and shape, the ray is said to be homogenous (Figure XXXIII, A.) It is plausible to assume that this condition ensues where all of the ray cells perform identical functions, that is, where there is little or no division of labour. The heterogeneous type (Figure XXXIII, B), on the other hand undoubtedly results incident to the relegation of unusual functions to certain cells of the ray, which as a result differ more or less in form and size from those which remain. For example the rays of the *Dillenias* are heterogeneous in type because certain cells become repositories for raphides (acicular crystals of calcium oxylate), and are deepened and shortened as a result. The remaining cells retain their

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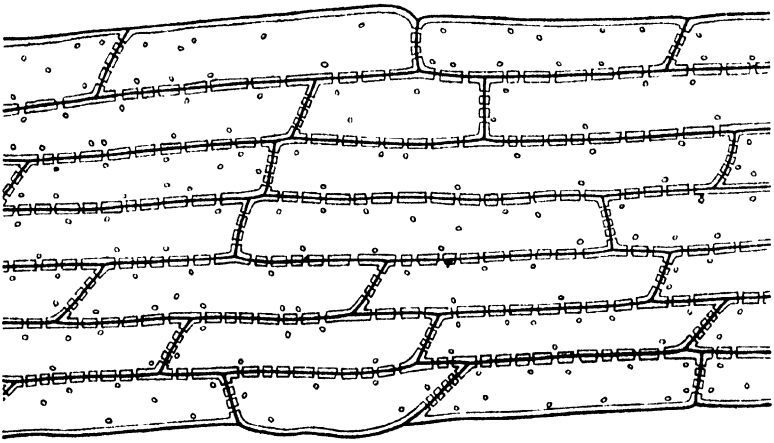
* In contrast to the diffused condition, compound or aggregate rays are comparatively rare in Indian trees. Many of the oaks (*Quercus serrata*) offer classic examples of the former type while aggregate rays feature the wood of other oaks, of *Alnus nepalensis*, etc.

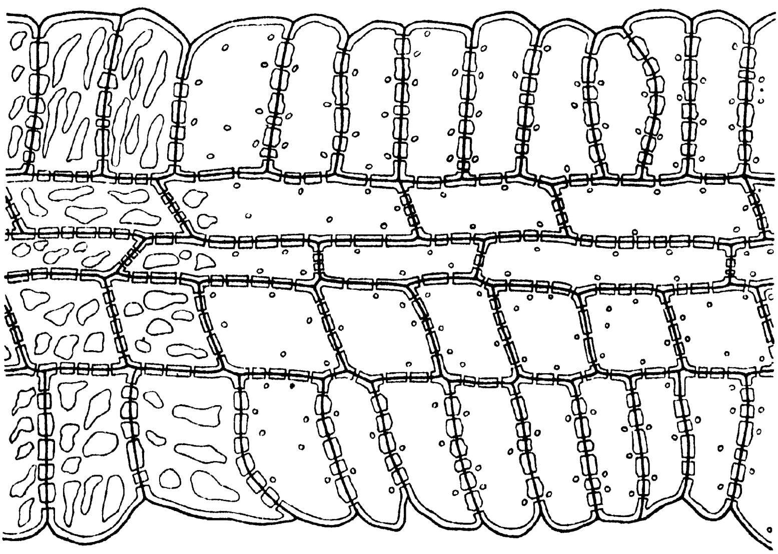
† *See* scale along margin of the plate.

‡ The wood rays of porous wood consist wholly of parenchyma.



Ganga Singh, del.

Figure 33A. Segment of a homogeneous ray of *Lagerstroemia Flos-Reginae*— × —385



Ganga Singh, del.

Figure 33B. Segment of a heterogeneous ray of *Kayea assamica*— × —385.

Photo. Zinco., July, 1925.—No. 708

[*To face page 108.*

normal functions meanwhile and present the usual characteristics of ray parenchyma and a heterogeneous ray is produced.

In many instances the "special" cells which are responsible for the heterogeneous ray are confined wholly to the ray margins and form one or more rows which stand out clearly against the remaining tissue. This feature is somewhat analogous to that arising from the presence of marginal ray tracheids in the radial bands of conifers but there the comparison ends; there is no connection between such cells from the physiological standpoint. In other woods the body of the ray has been invaded by cells of this sort and the ray as a result presents a very uneven structure as viewed laterally. The efficiency of such rays in radial-conduction is undoubtedly inhibited but the extent of this can only be conjectured.

(*b*) *Resin Canals.*

The presence and distribution of resin canals in porous timbers was discussed briefly on page 87. That they offer a valuable means of identification in those few woods in which they occur is patent.

The formation of the resin cavity in the secondary wood of dicotyledonous trees is similar in its essential details to that of conifers. There is no provision in the cambium, at least in so far as can be distinguished, for the canals that originate a few cells behind it in the new wood. The resin cavity proper arises schizogeneously, that is, through cell fission (the pulling apart of cells) in masses of parenchyma, in identically the same way as in coniferous trees. The central cells of groups of longitudinal parenchyma pull apart at the middle lamella, resin is excreted into the cavity thus resulting, and the opening enlarges until it attains to the size of the mature canal.

Plates VII and VIII illustrate two types of resin chambers as found in porous wood. In *sal* the canals course longitudinally and the cavities are aligned in tangential rows which extend for long distances through the wood in the form of concentric arcs. The individual canals anastamose frequently in the tangential plane and appear to be identical in every respect to the canals of deodar (Plate III). In fact the supposition may be

safely entertained that they belong to the same category as those of *Cedrus* (traumatic).

Dipterocarpus obtusifolius (Plate VIII) undoubtedly is more representative of the normal arrangement of resin canals in Dipterocarpaceous wood. In this species they are scattered individually through the tissue, and are imbedded in masses of parenchyma which communicate in turn with the wood rays. This type of arrangement is characteristic of *Dipterocarpus* species in contrast to the seemingly traumatic grouping of the *Shoreas* and *Hopeas*.

The radially aligned canal of an Anacardiaceous wood presents all the features of similar structures among the conifers. It occurs as a ray inclusion and the ray as a result has become fusiform. Radial canals of this type are present in such well known timbers as *Odina Wodier*, *Gluta travancorica* and *Melanorrhœa usitata* and are in certain cases the source of resins of value to man (*Boswellia serrata*).

In conclusion it is of interest to note that the resin canals of porous wood are as a rule restricted either to the longitudinal or to the radial type. Anacardiaceous and Burseraceous woods have but the radially aligned resiniferous cavities while the reverse applies in the Dipterocarps where longitudinal canals are always present and serve as a valuable aid in the identification of the woods of this family.

PART VIII.

The Identification of Woods.

The identification of woods depends in part on their varying anatomical structure and in part on those physical properties which are evident without the employment of stress in their determination. It offers a fascinating study which tests the powers of observation, and proficiency is attained only after much concentration and perseverance.

Wood identification on the part of the student presumes a fund of accumulated information bearing on the anatomical and physical properties of the various timbers and it is customary for convenience to arrange such data in tabular form or "keys." The supposition follows that given such a key and the proper instruments for the examination of a wood, its identification may follow with reasonable surety.

The key which follows is based on the macroscopic features of sixty of the most important timbers of India, that is, on those several features that may be determined either with the naked eye or with a pocket lens of the ordinary type, magnifying ten diameters. The dichotomous arrangement has been followed throughout and the alternatives which deal with the same topic and are coordinate in rank and hence comparable, are brought together in the key. Ease of manipulation is encouraged by indenting those which have happened to fall under even numbers.

A word of caution in the use of the key is in order since mistakes in the majority of cases result from inaccurate observation. It is futile to examine a surface of wood that has been exposed with a dull knife since more or less crushing of the tissue will have resulted which precludes accurate diagnosis. In examining the wood the pocket lens should always be held close to the eye and the object (block of wood) brought up toward the lens until it is in focus. In many timbers the anatomical features can be brought out by moistening the tissue with water while at other times the presence of water is a deterrent to accurate observation; it is best to try both ways.

Knowledge breeds knowledge and with continued use, a key becomes more serviceable. This should be borne in mind by those who approach the subject of wood identification for the first time and who are prone to condemn a key without fair trial.

Key to Sixty of the Most Important Indian Woods.

1. Wood without pores*; cells (tracheids) scarcely visible with a pocket lens, arranged evenly in radial rows, those near the end of the season's growth thicker walled and forming darker summerwood; rays very fine, scarcely distinct with a pocket lens 2

1. Wood with pores; pores larger than the surrounding cells, appearing as open or plugged orifices set in an opaque back ground (mechanical tissue); rays fine or broad . 7

2. Resin canals present in every ring, appearing as scattered dots, flecks, or minute openings . . . 3

2. Resin canals absent or if present, traumatic and arranged in tangential rows of five or more; rows occasional in seasonal rings 5

3. Resin canals large, conspicuous with a pocket lens on smooth cross section, appearing as dark streaks on face of boards; wood dull on fresh cut section, usually with resinous odor 4

3. Resin canals small, scarcely distinct with pocket lens on smooth cross section, indistinct on faces of boards; wood lustrous, without pronounced resinous odor . . *Picea Morinda* (*rai*).

4. Transition from spring to summerwood gradual; summerwood but little darker (denser) than the springwood; wood even grained . . *Pinus excelsa* (*kail*).

4. Transition from spring to summerwood abrupt; summerwood much darker and denser than the springwood; wood uneven grained . . *Pinus longifolia* (*chir*).

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* A pore is the cross section of a vessel or duct which is a tube-like articulated structure running with the grain of the wood. Vessels arise through fusion of a vertical row of cells the end walls of which become perforated.

5. Wood aromatic, with oily feel on fresh cut section; heartwood distinct from the sapwood 6

5. Wood not aromatic, with dry feel on fresh cut section; heartwood not distinct from the sapwood. *Abies Pindrow* (*pindrau*).

6. Wood pungently aromatic; summerwood appearing as a broad band in the outer part of the seasonal ring; tangential bands of traumatic resin canals usually present . . . . . . *Cedrus Deodara* (deodar).

6. Wood not pungently aromatic; summerwood appearing as a narrow dark line in the outer part of the seasonal ring; traumatic resin canals wanting . *Cupressus torulosa* (*devi-diar*).

7. Wood with longitudinal resin canals in addition to the pores; canals usually with white resinous contents 8

7. Wood without resin canals 11

8. Resin canals numerous to very numerous, arranged singly or in short tangential lines, evenly distributed through the wood; wood coarse textured; heartwood reddish brown . . *Dipterocarpus turbinatus* (*gurjun*), *D. tuberculatus* (*eng*), *D. alatus* (*kanyin*).

8. Resin canals fewer, in part at least arranged in tangential rows which appear at intervals and extend as white lines for long distances (an inch or more) in the wood; wood medium to fine textured; heartwood brown or yellowish brown 9

9. Pore contours indistinct; tyloses completely occluding all pores in the heartwood; rays moderately broad to broad . . *Shorea robusta* (*sal*); *Shorea obtusa* (*thitya*).

9. Pore contours distinct; tyloses not occluding all pores in the heartwood; rays fine to moderately broad. 10

10. Pores visible with the naked eye; heartwood yellowish brown; wood of medium texture and weight. *Hopea odorata* (*thingan*).

10. Pores not visible with the naked eye; heartwood pale yellowish brown to brown; wood fine textured and heavy . . . . . *Hopea parviflora* (*irubogam*).

11. Wood rays in echelon, that is, arranged in tiers and forming ripple marks on tangential section* . . 12

11. Wood rays not in echelon; ripple marks wanting on tangential section or if present, due to tiering of longitudinal elements 22

12. Pores in cross section connected by tangential lines or bands of parenchyma† which extend across a number of wood rays, or appearing as "eyelets" in angular areas of parenchyma which extend tangentially . . 13

12. Pores not connected by or imbedded in extensive tracts of parenchyma 21

13. Wood pale lemon yellow; heartwood wanting; many of the vessels occluded with white amorphous deposits . *Holoptelea integrifolia* (*kanju*).

13. Wood varying from greyish white, through shades of brown, red, or purple; many of the pores with dark gummy deposits 14

14. Wood rays fine but quite distinct with a pocket lens; ripple marks conspicuous, usually visible with the naked eye, very distinct with a pocket lens . . . 15

14. Wood rays very fine, scarcely distinct with a pocket lens; ripple marks not conspicuous, even with a pocket lens 19

15. Pores appearing as eyelets surrounded by a conspicuous halo of parenchyma; tangential lines of parenchyma more or less interrupted in cross sections . . . *Ougeinia dalbergioides* (*tanas*).

15. Pores not appearing as "eyelets"; parenchyma restricted about the pores; tangential lines of parenchyma continuous in cross sections 16

16. Tangential lines of parenchyma sharply defined, nearly straight, parallel; heartwood heavier than water‡. *Dalbergia Oliveri* (*tamalan*).

16. Tangential lines of parenchyma not sharply defined, more or less wavy, heartwood lighter than water . 17

* Ripple marks may arise in tangential section through a tiering of vertical elements, the rays not being included. See *Bombax malabaricum*, *Grewia tiliæfolia*, *Heritiera minor*, and *Fraxinus excelsior*. Such woods are not included in this group since the rays are not in echelon

† Longitudinal parenchyma.

‡ When thoroughly air dried.

17. Heartwood yellowish or golden brown, often with darker streaks . . *Pterocarpus Marsupium* (*bija sal*); *P. dalbergioides* (off color), (Andaman padauk).

17. Heartwood varying from reddish or purplish brown to dark red or purple 18

18. Heartwood reddish or purplish brown. *Pterocarpus macrocarpus*, (Burma padauk); *Pterocarpus dalbergioides*, (Andaman padauk).

18. Heartwood dark red or purplish red . . *Pterocarpus dalbergioides* (Andaman padauk).

19. Heartwood dark purplish red to almost black, heavier than water . . *Pterocarpus santalinus* (*red sanders*).

19. Heartwood brown to dark purplish brown, often with dark streaks, lighter than water . . . 20

20. Heartwood sweet scented on fresh cut section . *Dalbergia latifolia* (blackwood *or shisham*).

20. Heartwood not sweet scented on fresh cut section *Dalbergia Sissoo* (*sissoo*).

21. Pores large, visible with the naked eye; wood greyish or brownish white, coarse textured, readily dented with the finger nail . . . . . . *Bombax insigne* (*didu*).

21 Pores minute, scarcely distinguishable with a hand lens; wood pale lemon yellow or cream colored, extremely fine textured, very hard . . . . . *Chloroxylon Swietenia* (*satinwood*).

22. Longitudinal parenchyma visible in cross sections with a pocket lens 23

22. Longitudinal parenchyma not visible in cross sections with a pocket lens 54

23. Parenchyma forming a wall or halo about the pores (paratracheal) or in more or less continuous tangential bands 24

23. Parenchyma diffused through the wood, appearing punctate or as very fine tangential lines connecting wood rays and forming a reticulum 47

24. Parenchyma in more or less continuous bands which may or may not include the pores 25

24. Parenchyma confined to the vicinity of the pores or in addition, forming terminal bands which delimit growth rings 36

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25. Bands of parenchyma confined to the springwood and including the spring pores; wood ring-porous . 26

25. Bands of parenchyma disposed through the ring or terminal; wood diffuse or ring-porous . . . 27

26. Tyloses generally abundant; vessels occasionally with white gummy deposits; wood oily, dark golden yellow or brown, darkening with age . *Tectona grandis*, (teak).

26. Tyloses wanting; vessels with dark gummy deposits; wood dry, brick red to dark reddish brown . *Cedrela Toona* (*toon*).

27. Bands of parenchyma disposed through the ring; tyloses very numerous, completely occluding the pores in the heartwood; heartwood pale red . *Lagerstroemia Flos-Reginæ* (*jarul*, *ajar* or *pyinma*).

27 Bands of parenchyma disposed through the ring or terminal; tyloses sparse or wanting in the heartwood; pores not completely occluded; heartwood greenish or brownish white to yellowish olive or reddish brown . 28

28. Bands of parenchyma with even margins arranged without respect to the pores 29

28. Bands of parenchyma with uneven margins, arising through fusion of paratracheal parenchyma . . 33

29. Wood ring-porous; tangential bands of parenchyma sporadic and irregular in distribution, occurring at intervals and wanting in many rings . . *Cedrela Toona* (*toon*).

29. Wood diffuse-porous; tangential bands of parenchyma not sporadic 30

30. Pores diffused through the wood, solitary or in radial rows of 2—3 31

30. Pores irregularly disposed, arranged in oblique, radial, flame-like groups of a half dozen or more . 32

31. Wood hard, fine textured; heartwood yellowish brown to rich reddish brown (russet) . . . . . *Chickrassia tabularis* (*chickrassi*).

31. Wood soft, rather coarse-textured; heartwood greenish yellow (olive) to greenish brown . . . *Michelia Champaca* (*champ*).

32. Tangential bands of parenchyma very numerous; heartwood dark reddish brown, heavier than water . *Mesua ferrea* (*nahor*).

32. Tangential bands of parenchyma at short intervals; heartwood pale to dark brown, lighter than water . *Calophyllum tomentosum* (*poon*); *Calophyllum spectabile* (*lal chuni*).

33. Wood ring-porous; pores in the spring wood one or more layers thick; heartwood greyish white. *Fraxinus excelsior* (ash *or sum*).

33. Wood diffuse-porous; heartwood olive or yellowish grey to dark brown, often with streaks of darker colour 34

34. Pores visible with the naked eye; wood medium textured 35

34. Pores not visible with the naked eye; wood fine-textured . . . *Anogeissus latifolia* (*bakli or dhaura*).

35. Parenchyma abundant about the pores; pores appearing as "eyelets" which may coalesce; seasonal zones usually marked by conspicuous lines of parenchyma *Terminalia tomentosa* (*sain, mutti or taukkyan*).

35. Parenchyma restricted about pores; seasonal zones not marked by conspicuous bands of parenchyma . *Terminalia bialata* (*chuglam*)

36. Vessels with dark gummy deposits . . 37

36. Vessels without dark gummy deposits . 40

37. Pores appearing as "eyelets," surrounded by extensive tracts of parenchyma; heartwood dark brown, often with lighter or darker streaks. *Albizzia Lebbek* (*siris*).

37. Pores not appearing as "eyelets"; parenchyma restricted about the pores 38

38. Wood rays plainly visible with the naked eye; vessels conspicuous on faces of boards 39

38. Wood rays very fine, not visible with the naked eye; vessels not conspicuous on faces of boards . . *Xylia dolabriformis* (*pyinkado*)

39. Seasonal zones marked by fine tangential lines of parenchyma; pores occasionally with white amorphous deposits . . . . *Acacia Catechu* (cutch).

39. Seasonal zones not marked by tangential lines of parenchyma or, if present, very indistinct; pores without white amorphous deposits . . *Acacia arabica* (babul).

40. Wood ring-porous; pores larger or more numerous in the early part of the ring 41

40. Wood diffuse-porous 43

41. Summerwood pores thick walled, those near the periphery of the ring usually connected by parenchyma; tyloses sparse; vertical elements in echelon *Fraxinus excelsior* (ash or *sum*).

41. Summerwood pores thin walled, not connected by parenchyma; tyloses generally abundant; vertical elements not in echelon 42

42. Vessels without white amorphous deposits; heartwood yellowish or greyish white, lustrous, dry, unscented . . . *Gmelina arborea* (*shivan or gumhar*).

42. Vessels often with white amorphous deposits; heartwood dark golden yellow to brown, dull, oily, characteristically scented* . *Tectona grandis* (teak).

43. Wood rays plainly visible with the unaided eye; vessels often with white amorphous deposits; wood very coarse-textured . . *Artocarpus Chaplasha* (*chaplash or chain*), *Artocarpus hirsuta* (*aini*); *Artocarpus Lakoocha* (*lakuch*).

43. Wood rays not plainly visible with the unaided eye; vessels without white amorphous deposits; wood medium to fine-textured 44

44. Wood rays scarcely visible with a hand lens, very fine and close; heartwood as heavy or nearly as heavy as water 45

44. Wood rays plainly visible with a hand lens, close or somewhat distant; heartwood appreciably lighter than water 46

45. Pores not visible with the naked eye; parenchyma restricted about the pores; growth rings indistinct, usually marked by layers of fibrous tissue nearly free of pores . *Anogeissus latifolia* (*bakli or dhaura*).

* The odour of teak has been described as resembling that of "old leather."

45. Pores visible with the naked eye, often appearing as " eyelets " in tracts of parenchyma; growth rings usually marked by tangential bands of parenchyma . . *Terminalia tomentosa* (*sain*, *mutti* or *taukkyan*).

46. Wood with tangential strings of parenchyma at intervals in addition to that about the pores . *Mangifera indica* (*amb* or mango).

46. Wood without tangential strings of parenchyma; parenchyma confined to the vicinity of the pores . . *Duabanga sonneratioides* (*lampatia*, *band* or *hulla*).

47. Vessels clearly visible with a lens, showing as streaks on face of boards; wood coarse to medium-textured . . . . 48.

47. Vessels extremely fine, scarcely visible with a hand lens; wood extremely fine-textured . . . 53

48. Wood rays fine, not clearly visible without a hand lens; wood medium hard to hard 49

48. Wood rays coarse, clearly visible with the naked eye; wood soft, readily dented with the finger nail . *Bombax malabaricum* (*simul*).

49. Vessels diffused through the wood, solitary or in short radial rows; wood rays plainly visible with a hand lens 50

49. Vessels in oblique, radial, flame-like groups; wood rays extremely fine, scarcely visible with a hand lens *Castanopsis Hystrix* (*hingori*).

50. Heartwood greyish or yellowish white to light greyish brown, often mottled, of medium weight . 51

50. Heartwood dull to dark red or claret coloured, as heavy or nearly as heavy as water . . . 52

51. Tangential lines of parenchyma distinct with a lens, forming a reticulum with the wood rays; pores solitary or more rarely in radial groups of 2—3; wood smooth-textured, rich greyish brown . . . *Juglans regia* (walnut).

51. Tangential lines of parenchyma indistinct with a lens; majority of the pores in radial rows of three or four; wood coarse-textured, greyish or yellowish white . . *Anthocephalus Cadamba* (*kaddam*).

52. Tyloses wanting; pores open or occluded with gummy deposits; longitudinal elements in echelon . *Heritiera minor* (*sundri*).

52. Tyloses very abundant; longitudinal elements not in echelon . . . . . . *Careya arborea* (*kumbi*).

53. Parenchyma in tangential lines, distinct with a lens and forming a reticulum with the wood rays; heartwood jet black, rarely with brownish streaks, heavier than water . . . . . *Diospyros Ebenum* (ebony).

53. Parenchyma appearing punctate, diffused through the fibrous tissue; wood yellow, lighter than water . *Adina cordifolia* (*haldu*)

54. Wood ring-porous 55

54. Wood diffuse-porous 58

55. Vessels with dark gummy deposits; heartwood brick red to dark reddish brown . *Cedrela Toona* (*toon*).

55. Vessels without dark gummy deposits; heartwood pale greyish or yellowish white to yellowish or dark golden brown 56

56. Vessels often with white amorphous deposits; wood scented, oily; contour of growth rings often irregular . *Tectona grandis* (teak)

56. Vessels without white deposits; wood dry, unscented; seasonal zones more or less regular . . . 57

57. Summerwood pores nearly as large as those in the springwood, the majority solitary; heartwood pale yellowish or greyish white . . *Gmelina arborea* (*shivan* or *gumhar*).

57. Summerwood pores minute, the majority in nests or short tangential lines; heartwood yellowish brown, darkening with age . . *Morus alba* (white mulberry or *tut*)

58. Longitudinal elements in echelon; vessels of heartwood often with white amorphous deposits . *Grewia tiliaefolia* (*dhaman*).

58. Longitudinal elements not in echelon; white deposits wanting 59

59. Pores not visible with naked eye; vessels not conspicuous on face of boards; wood fine-textured, hard, heavy 60

59. Pores visible with naked eye, vessels conspicuous on face of boards; woods coarse-textured, soft to medium hard, light to medium heavy 62

60. Wood rays fine, visible with the naked eye; wood yellow to pale yellowish white . *Buxus sempervirens*, (boxwood or *papri*).

60. Wood rays not visible with the naked eye; heartwood olive grey to brown or purplish brown . . 61

61. Pores in radial rows of 2—6; wood straight-grained, often mottled with concentric bands which extend tangentially . . *Terminalia Manii* (black chuglam).

61. Pores in radial rows of 2—4; wood with interlocked and often curly grain, often with irregular purplish brown mottling (heartwood) . . *Anogeissus latifolia* (*bakli* or *dhaura*).

62. Heartwood red or reddish brown; seasonal rings narrow to moderately wide 63

62. Heartwood greyish or yellowish white; seasonal rings very wide . *Anthocephalus Cadamba* (*kaddam*).

63. Tyloses abundant; wood dull, dark red, vinegar scented when fresh cut; ribbon grain not pronounced on radial section . . *Bischofia javanica* (*uriam or irum*).

63. Tyloses spares; wood lustrous, light red or reddish brown, without pronounced odour; ribbon grain pronounced on radial section . *Calophyllum spectabile* (*lal chuni*).

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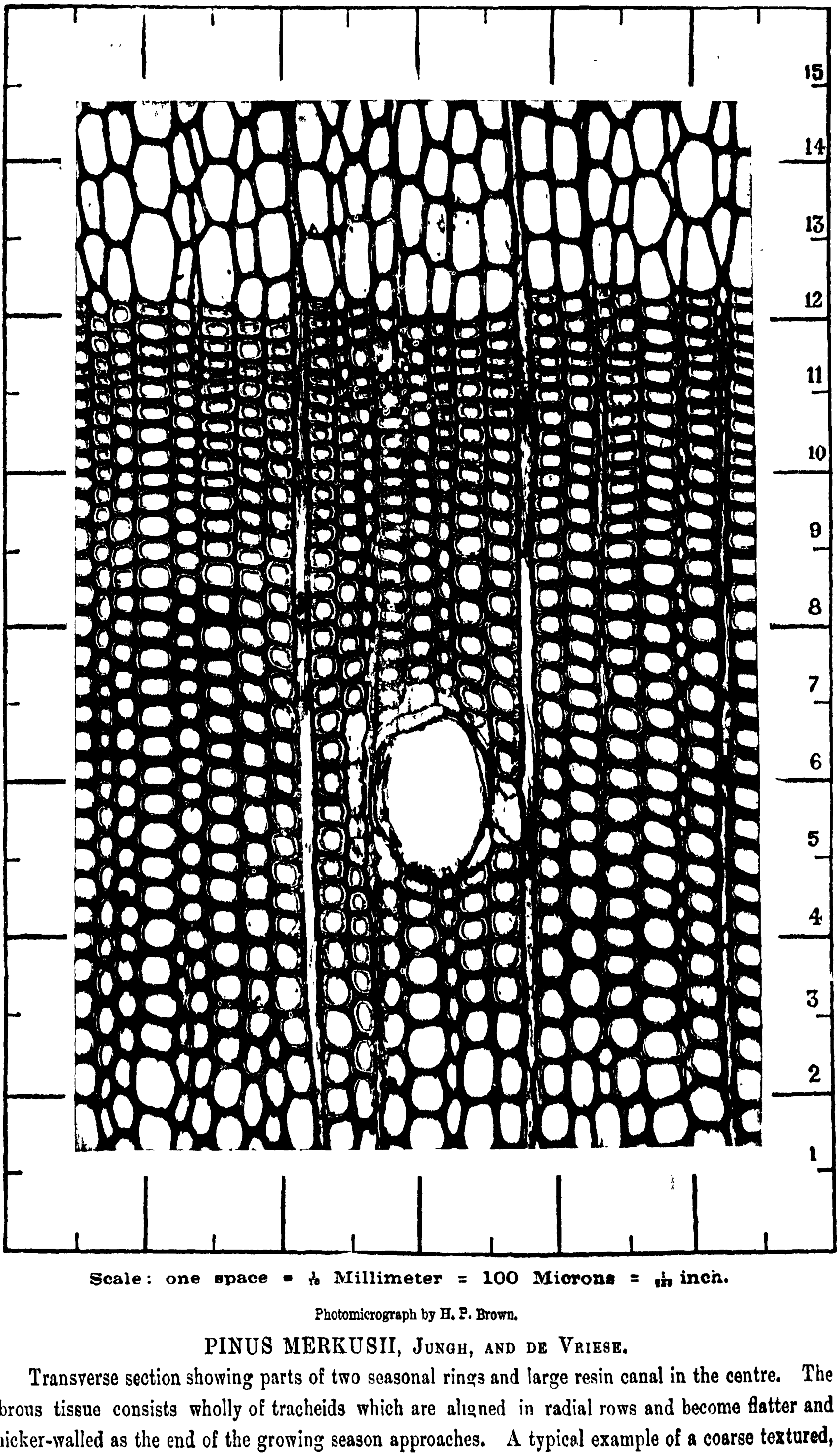
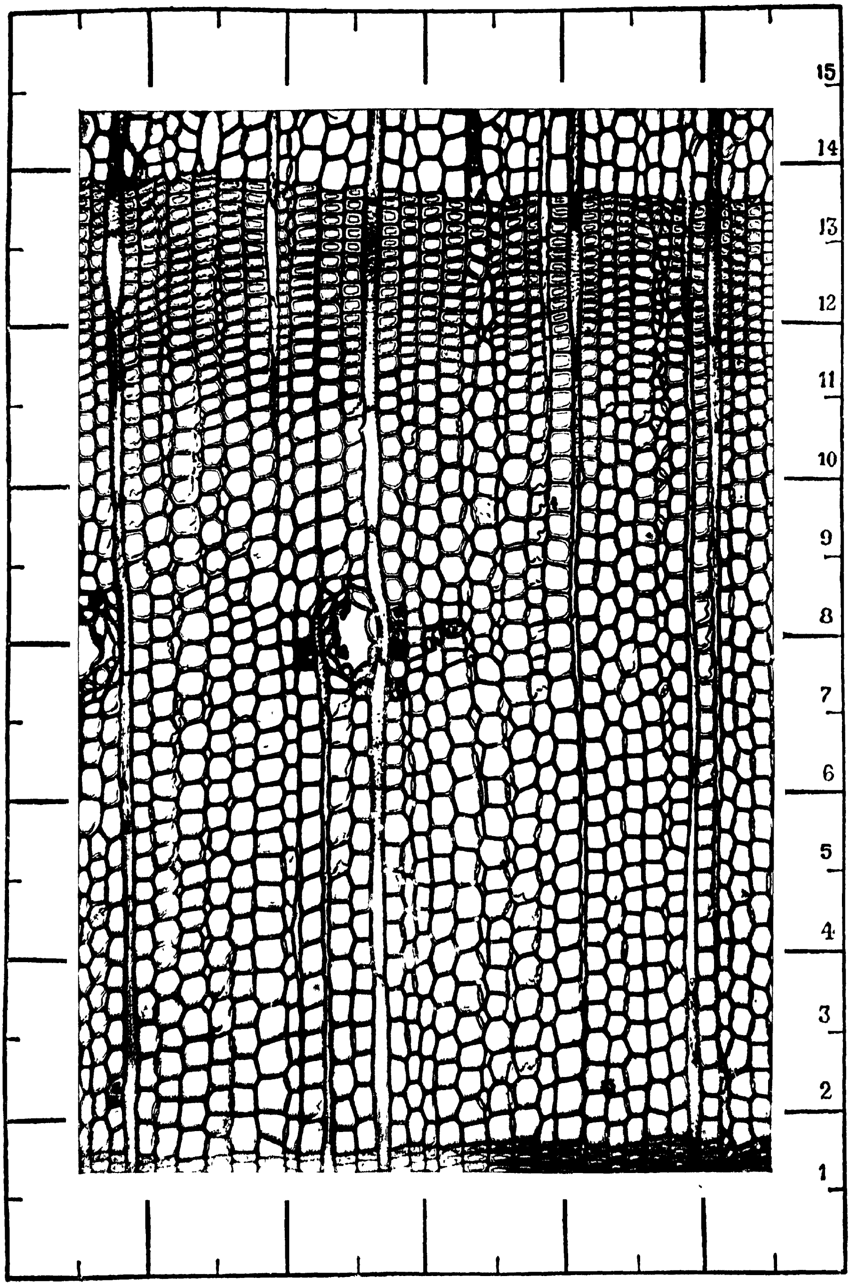


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

PINUS MERKUSII, Jungh, and de Vriese.

Transverse section showing parts of two seasonal rings and large resin canal in the centre. The fibrous tissue consists wholly of tracheids which are aligned in radial rows and become flatter and thicker-walled as the end of the growing season approaches. A typical example of a coarse textured, non-porous wood.

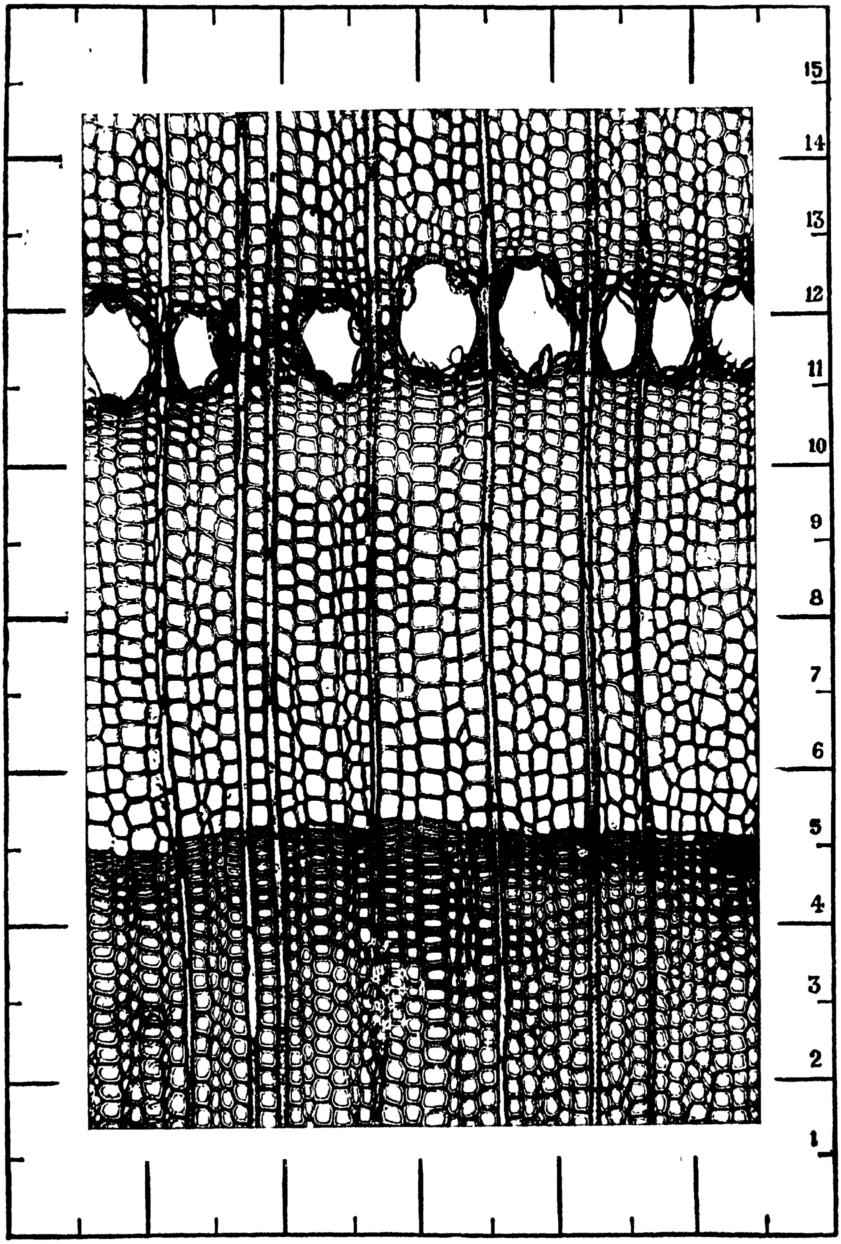


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

PICEA MORINDA, LINK.

Transverse section showing one complete ring and resin canal. The resin canals of spruce are smaller than those of pine and possess thick-walled, epithelial parenchyma. A coniferous wood of medium texture.

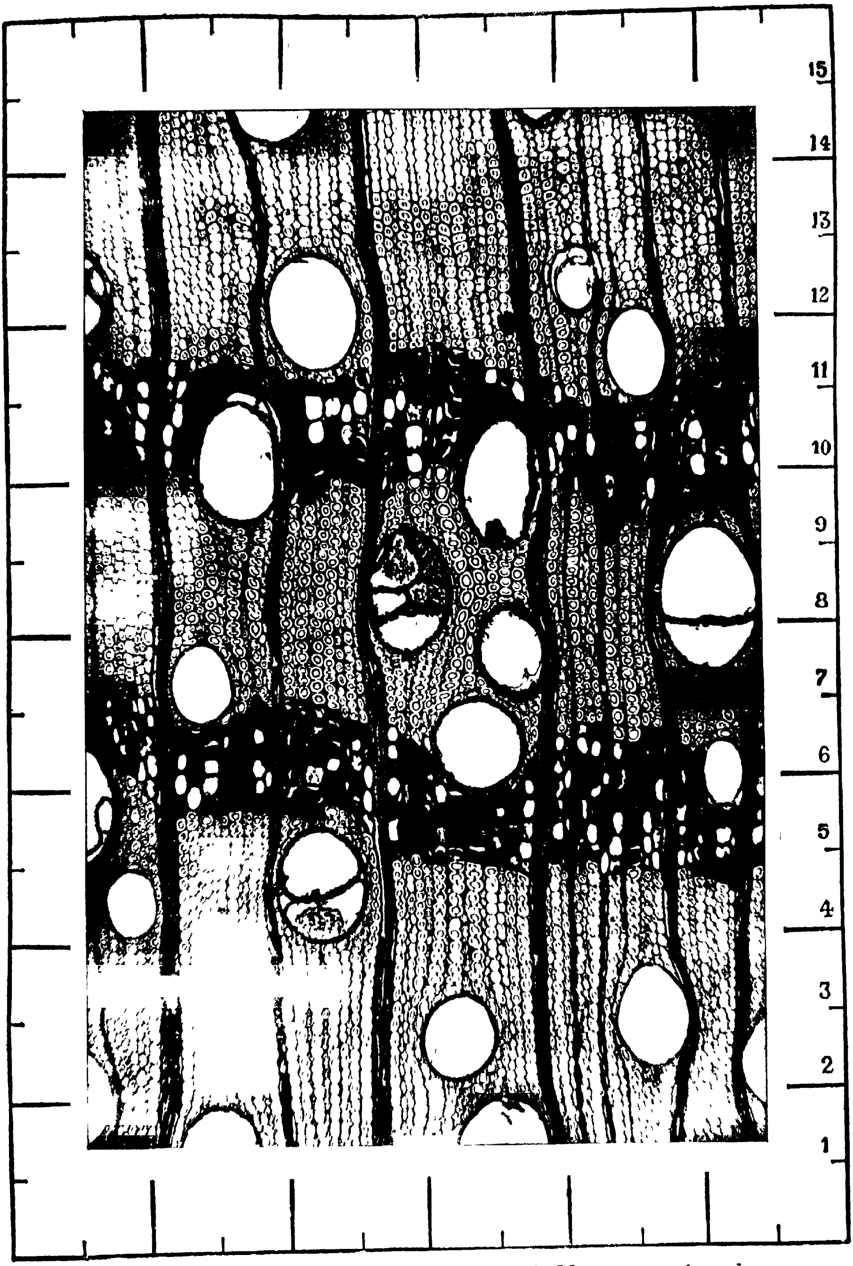


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{254}$ inch.

Photomicrograph by H. P. Brown.

CEDRUS DEODARA, Loudon.

Transverse section showing parts of two seasonal rings and a tangentially aligned row of traumatic resin canals which anastomose in the tangential plane. Resin canals are normally absent from deodar wood but frequently develop as a result of injury.

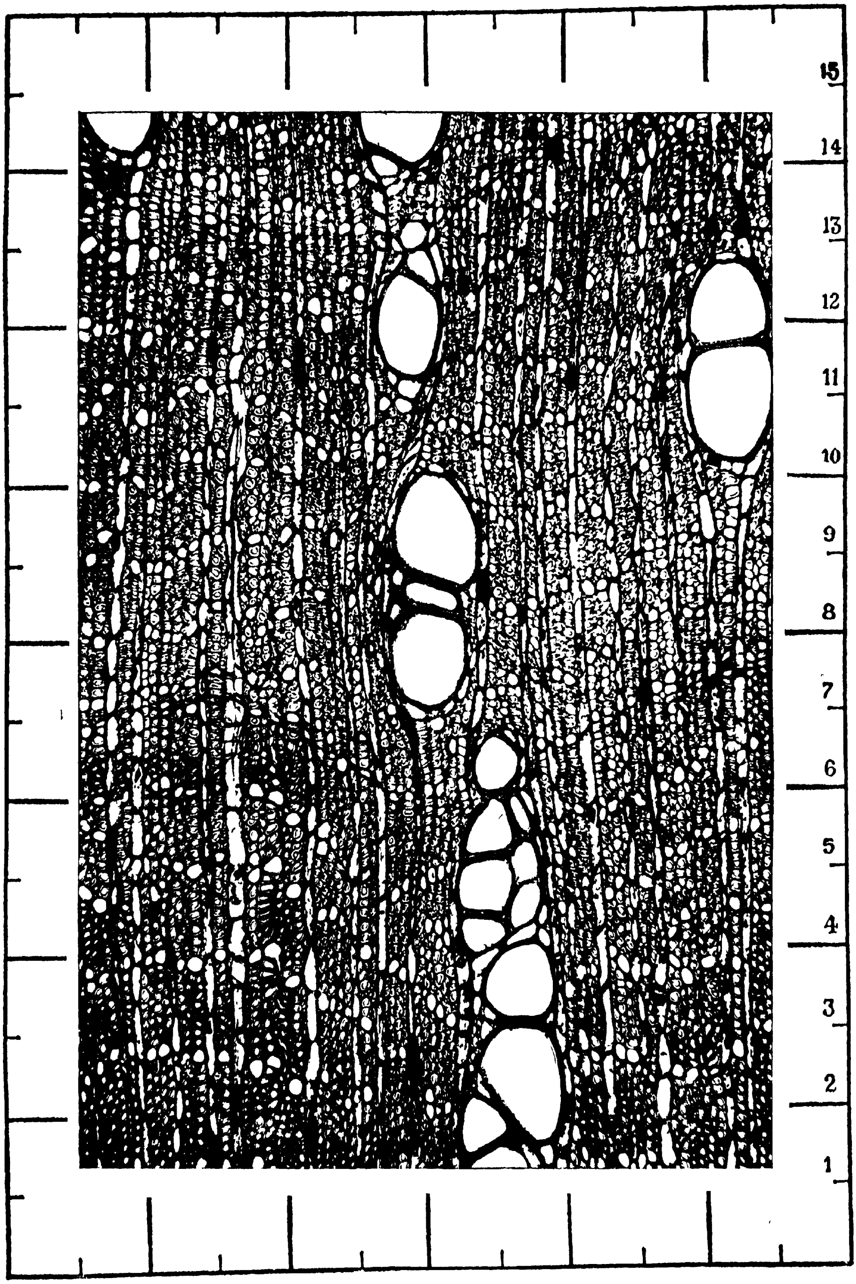


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

KAYEA ASSAMICA, King and Prain.

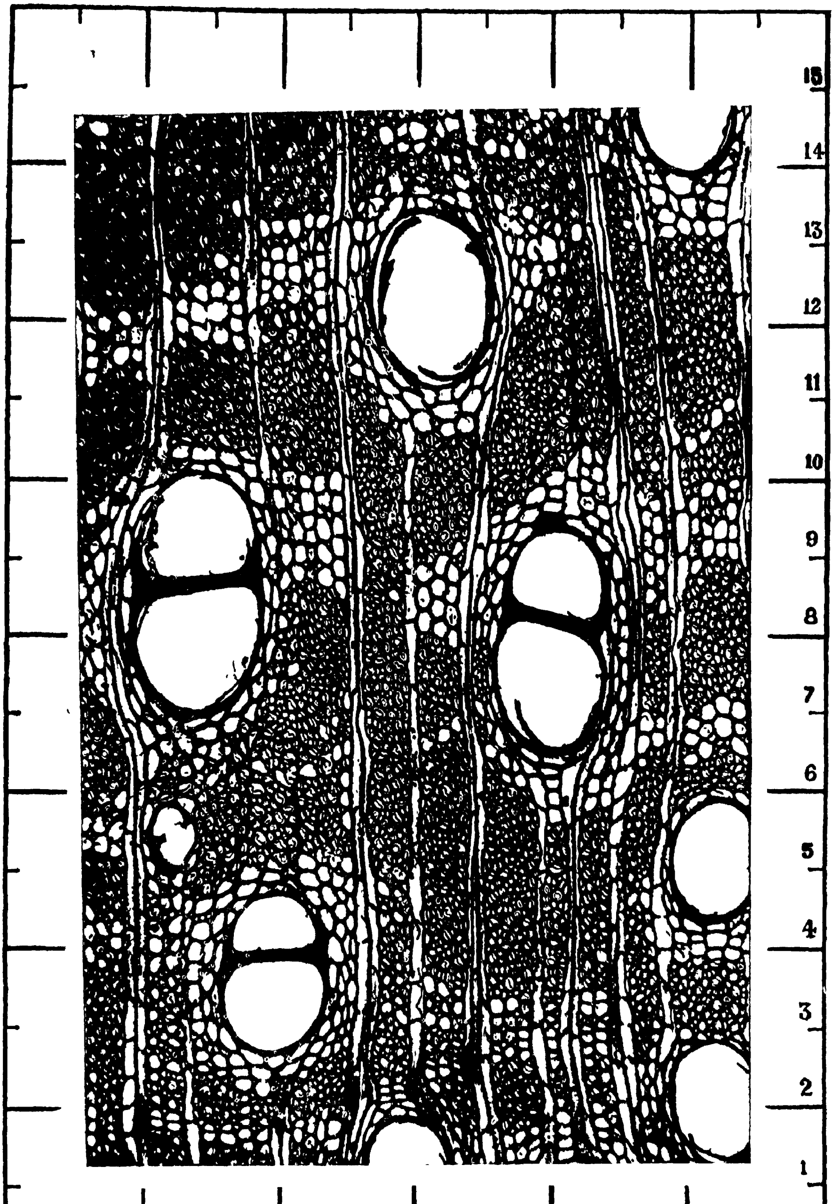
Transverse section showing the tangential bands of longitudinal parenchyma which feature the woods of the *Guttiferæ* Such bands connect wood rays but extend more or less irrespective of the vessels. In this species they are evidently not correlated with seasonal growth.



Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

DIOSPYROS MELANOXYLON, Roxb.

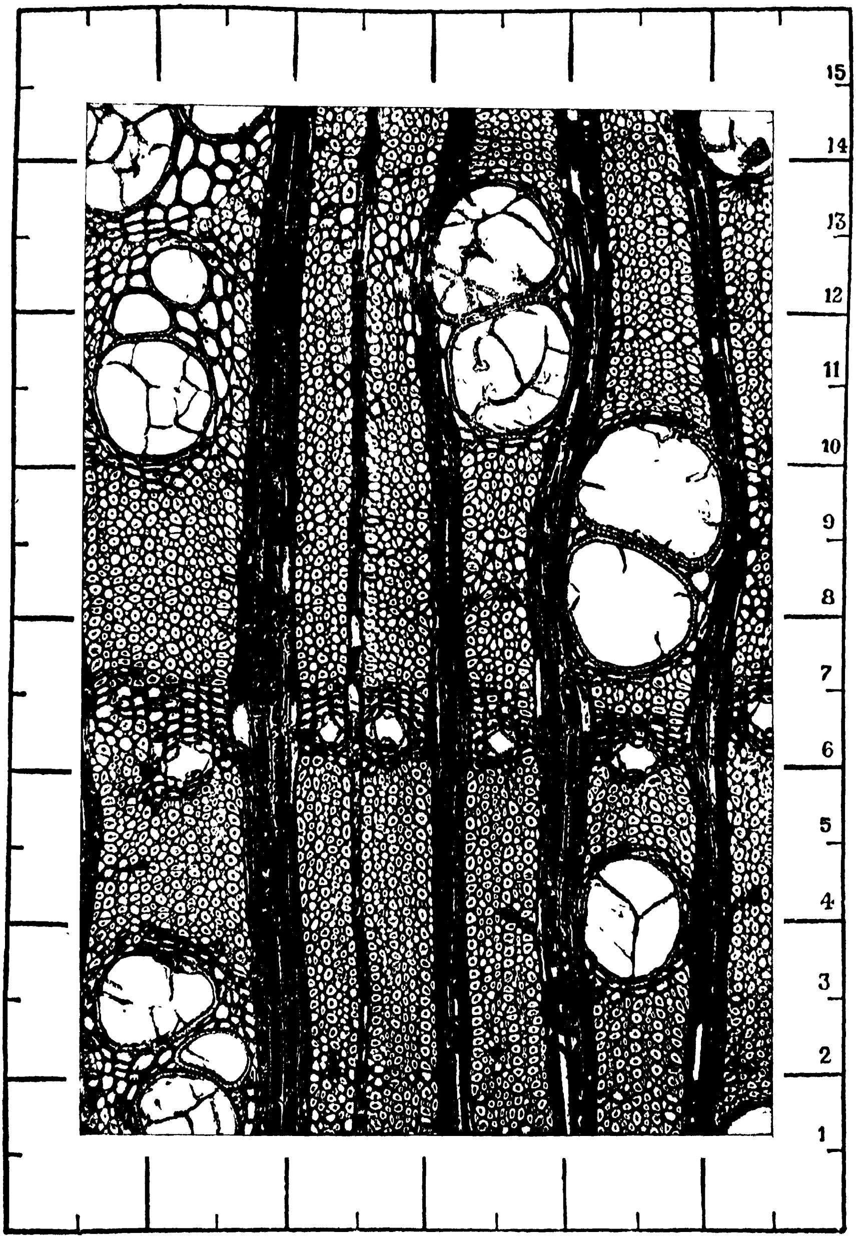


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{254}$ inch.

Photomicrograph by H. P. Brown.

DALBERGIA SISSOO, Roxb.

Transverse section illustrating longitudinal paratracheal parenchyma about the pores. The tracts of parenchyma tend to extend tangentially across wood rays to connect pores.

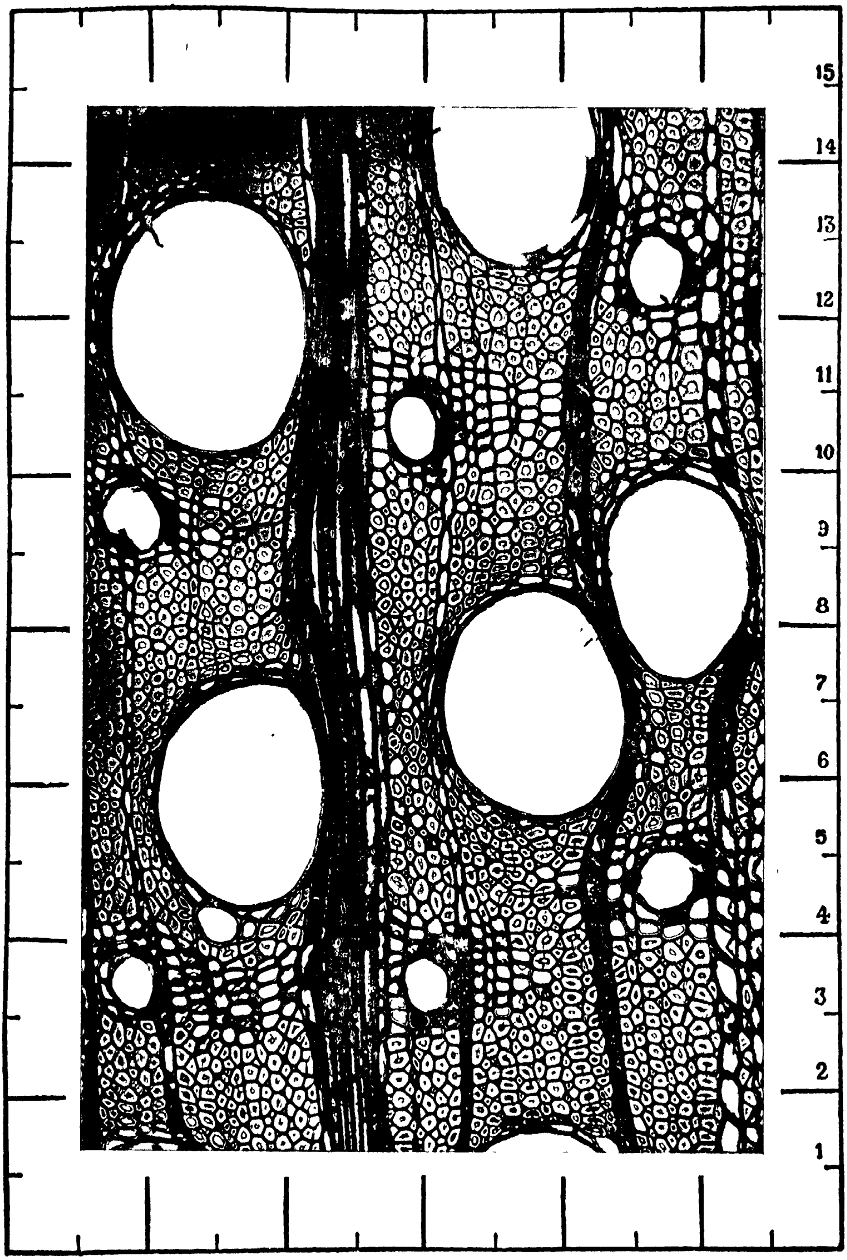


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

SHOREA ROBUSTA, Gaertn f.

Transverse section showing tangentially aligned resin canals which form rows at intervals in the wood and suggest the traumatic cavities of deodar wood. The pores exhibit tyloses and the wood rays are filled with a dark infiltration product. Mechanical cells are very numerous and here and there the fibrous tissue is dotted with longitudinal parenchyma.

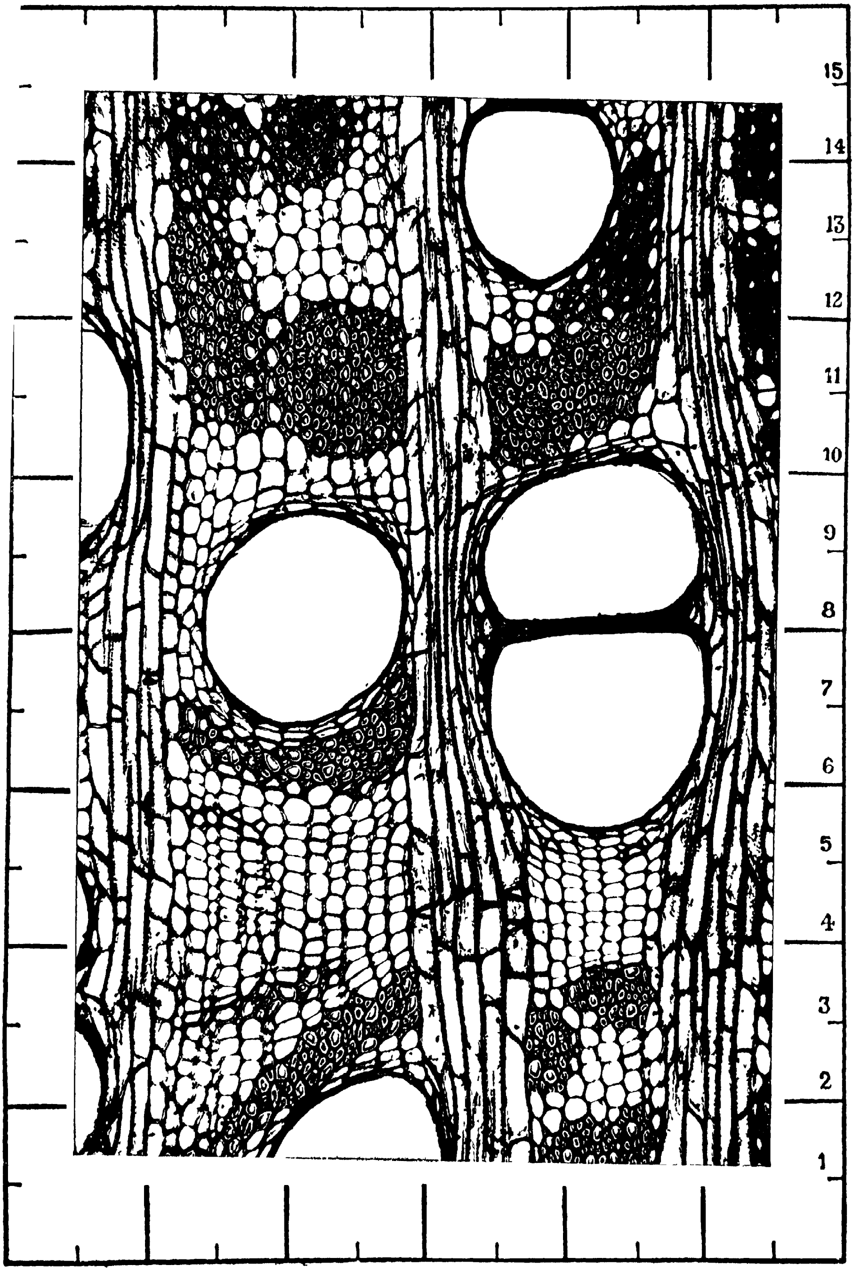


Scale: one space = 1/10 Millimeter = 100 Microns = 1/250 inch.

Photomicrograph by H. P. Brown.

DIPTEROCARPUS OBTUSIFOLIUS, Teysm.

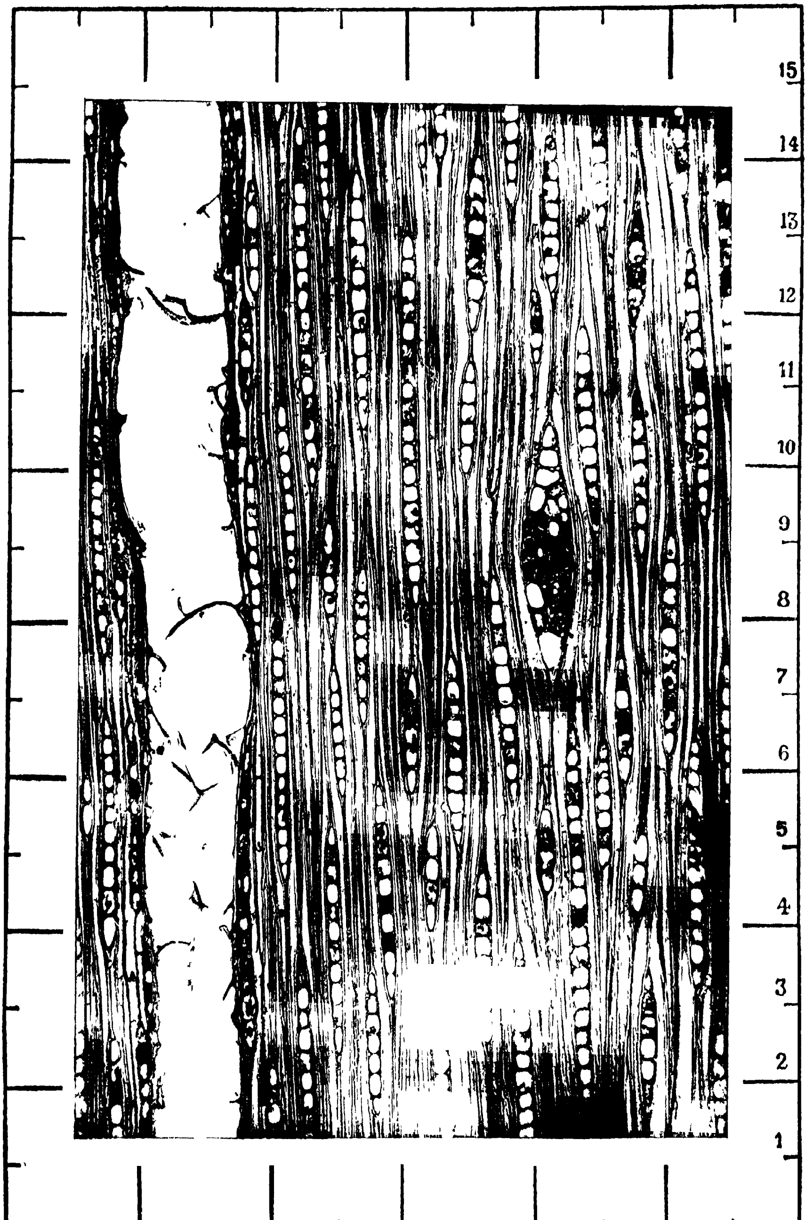
Transverse section illustrating the relative coarse-textured nature of the wood with its large pores and broad wood rays. Tyloses are not in evidence in the vessels but resin canals are numerous, embedded in masses of longitudinal parenchyma adjacent to wood rays.



Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

CORDIA MYXA, Linn.

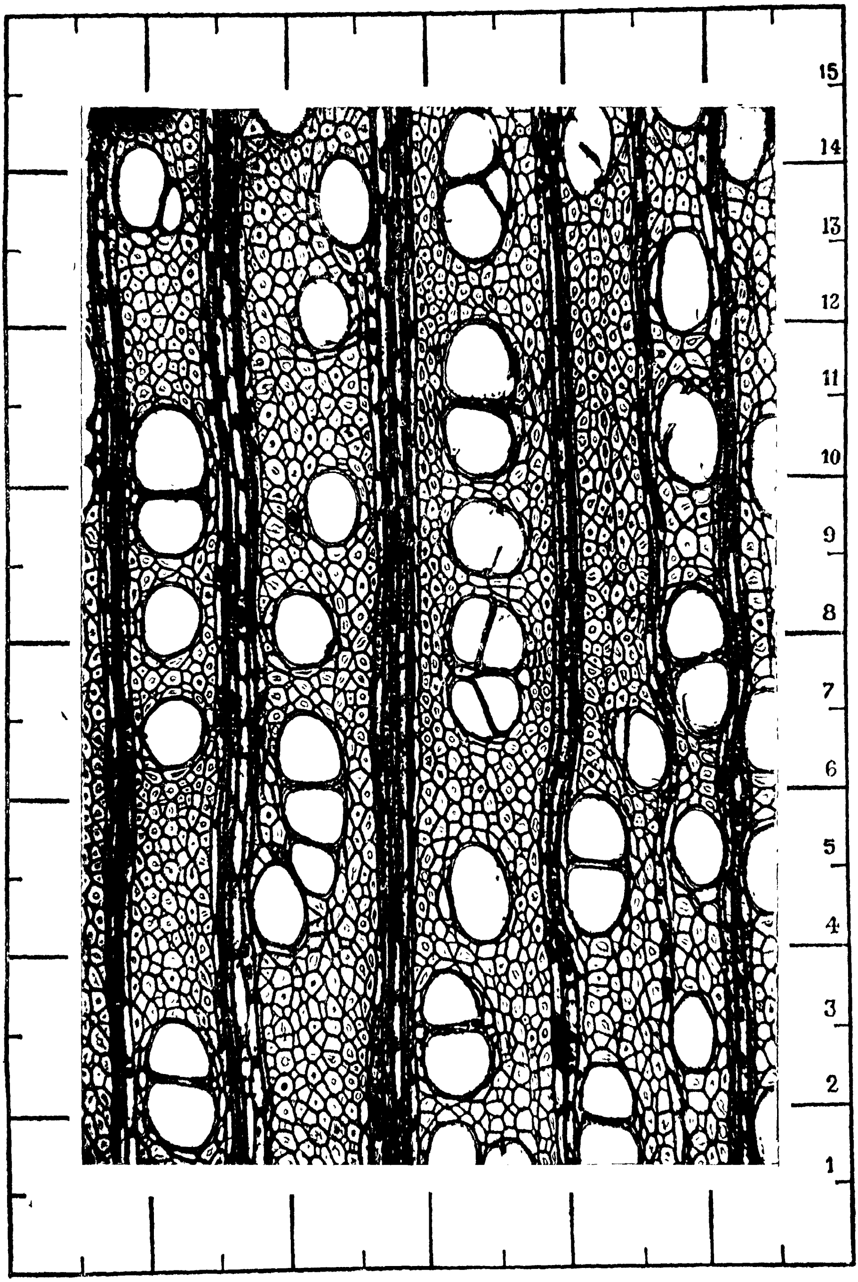


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrogram by H. P. Brown.

GLUTA TRAVANCORICA, Bedd.

Tangential section affording a sectional view of a vessel at the left. numerous uniseriate wood rays, and a fusiform ray containing a radially aligned canal. Radial canals, unaccompanie by those of the longitudinal type, are present in many of the woods belonging to the *Anacardiaceae*.

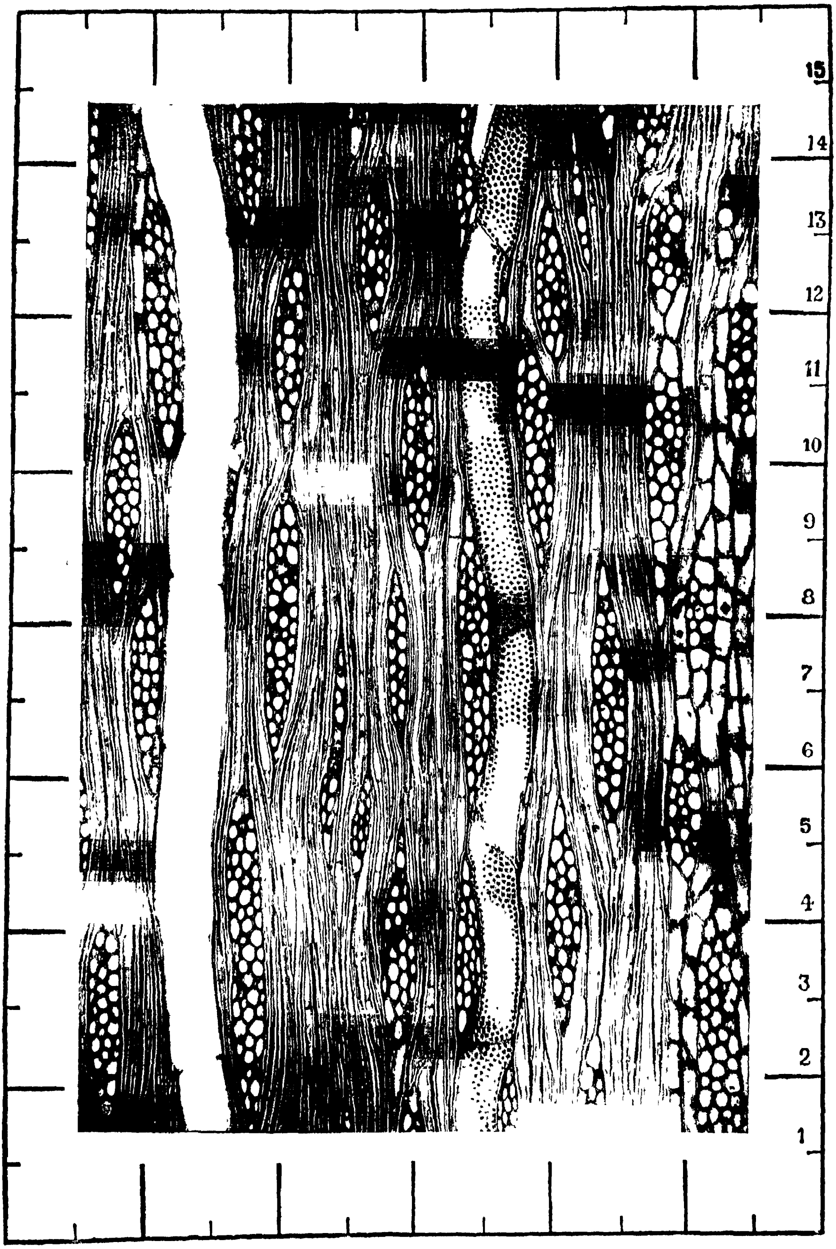


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

RHIZOPHORA MUCRONATA, Lamk.

Plate XII.



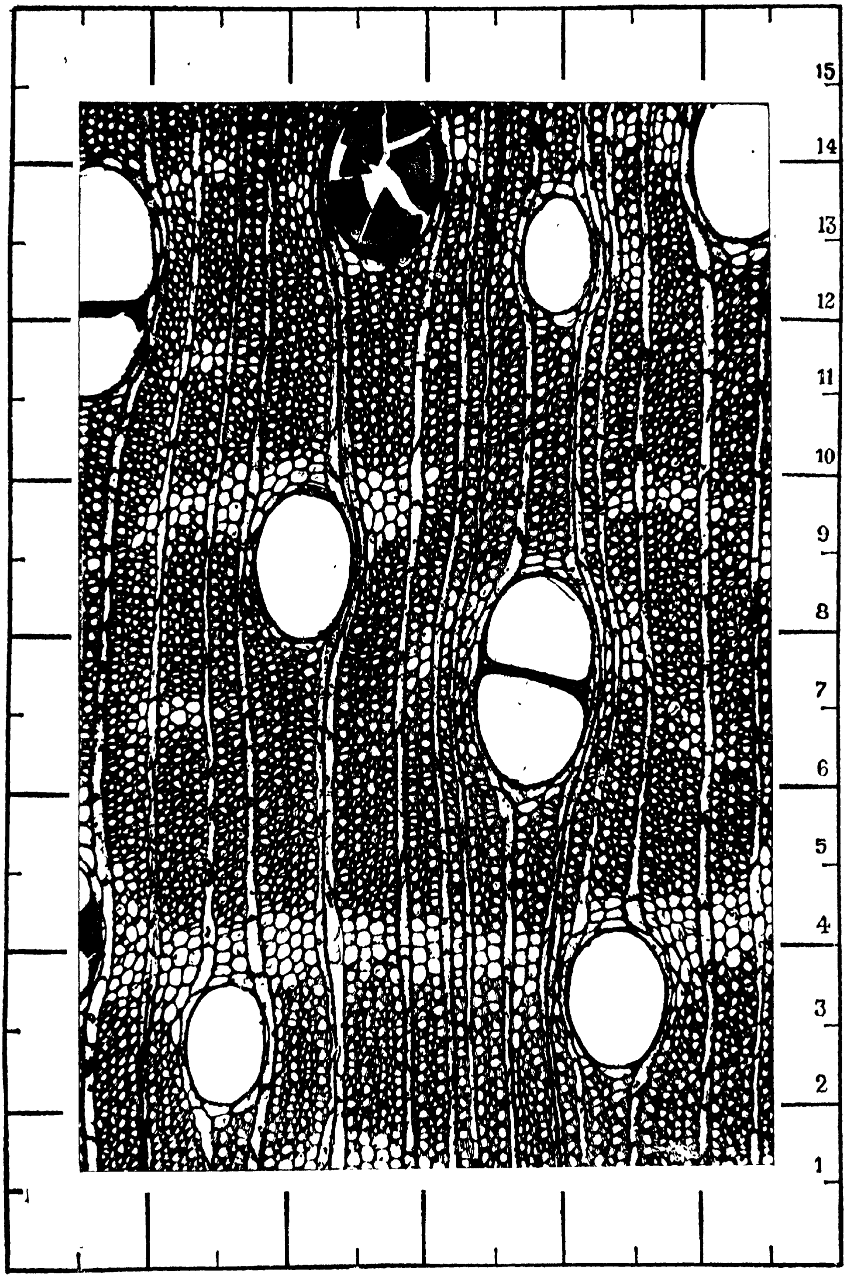
Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

TECTONA HAMILTONIANA, Wall.

Tangential section showing vessels in lateral sectional and lateral surface view. The pits on the lateral vessel-walls are crowded and hexagonal in contour. Numerous fusiform wood rays are present, separated by septate fibres while fusiform parenchyma rows may be seen on the right.

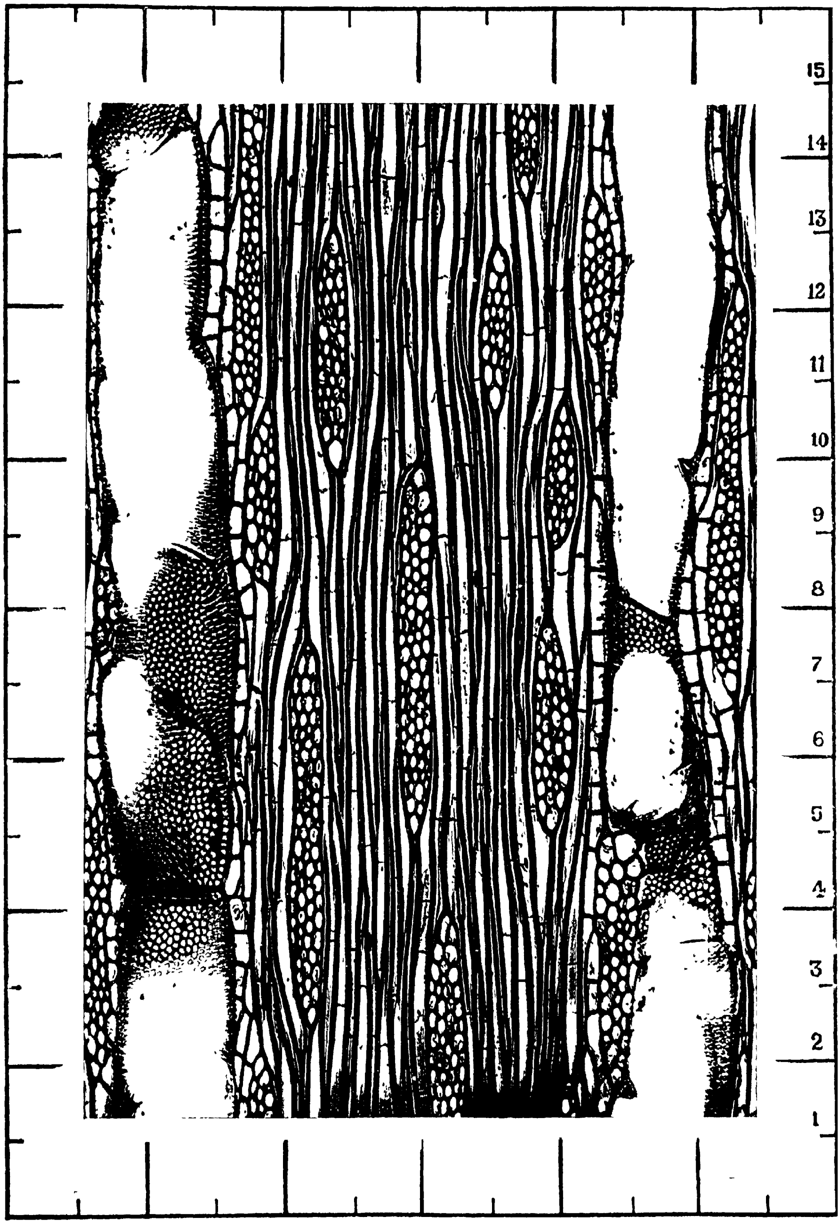
Plate XIII.



Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

PTEROCARPUS MARSUPIUM, Roxb.



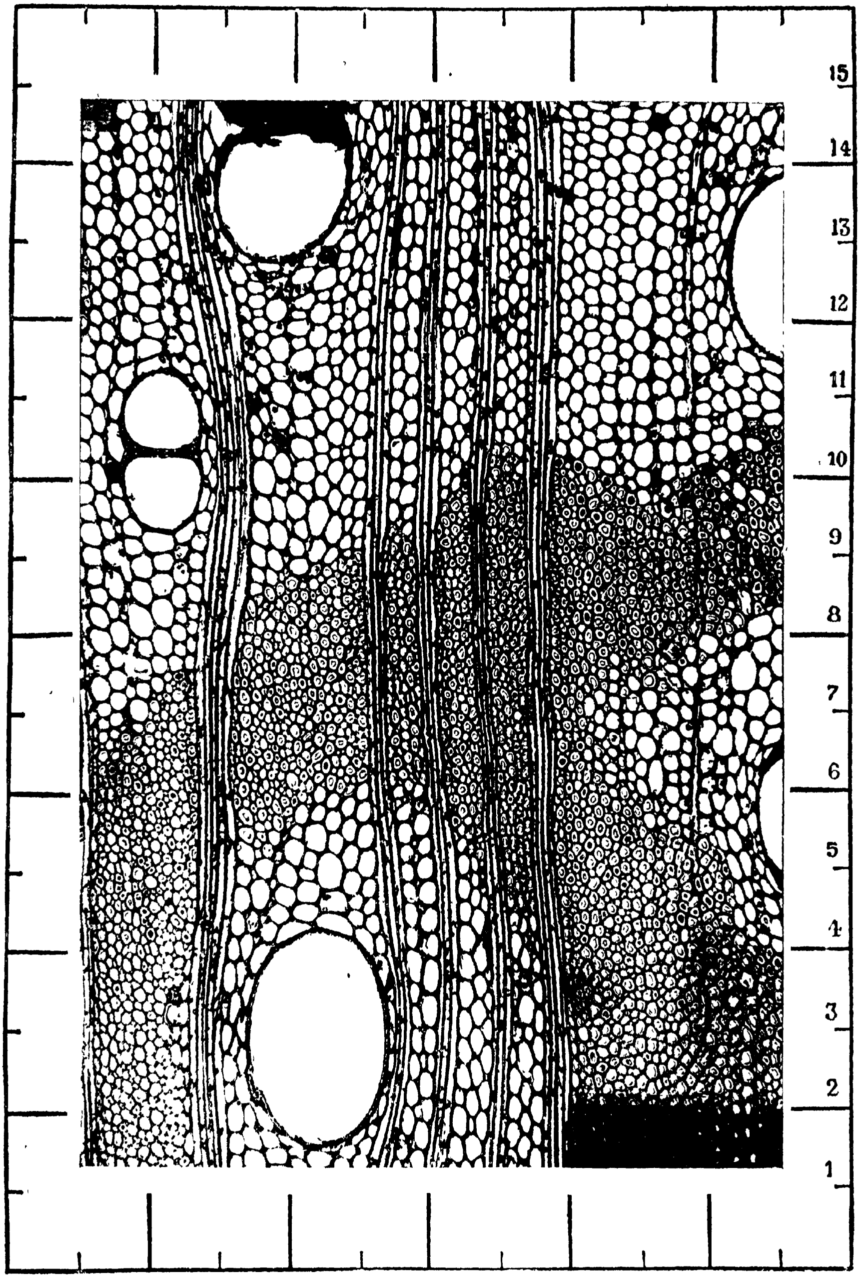
Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

GMELINA ARBOREA, Roxb.

Tangential section. The pitting on the lateral walls of the vessels shows exceptionally well. The pits are clearly bordered and while numerous, are not so crowded as to have become hexagonal. Paratracheal parenchyma borders the vessels laterally and is accompanied by rather large wood rays and tracts of septate fibres.

Plate XV.

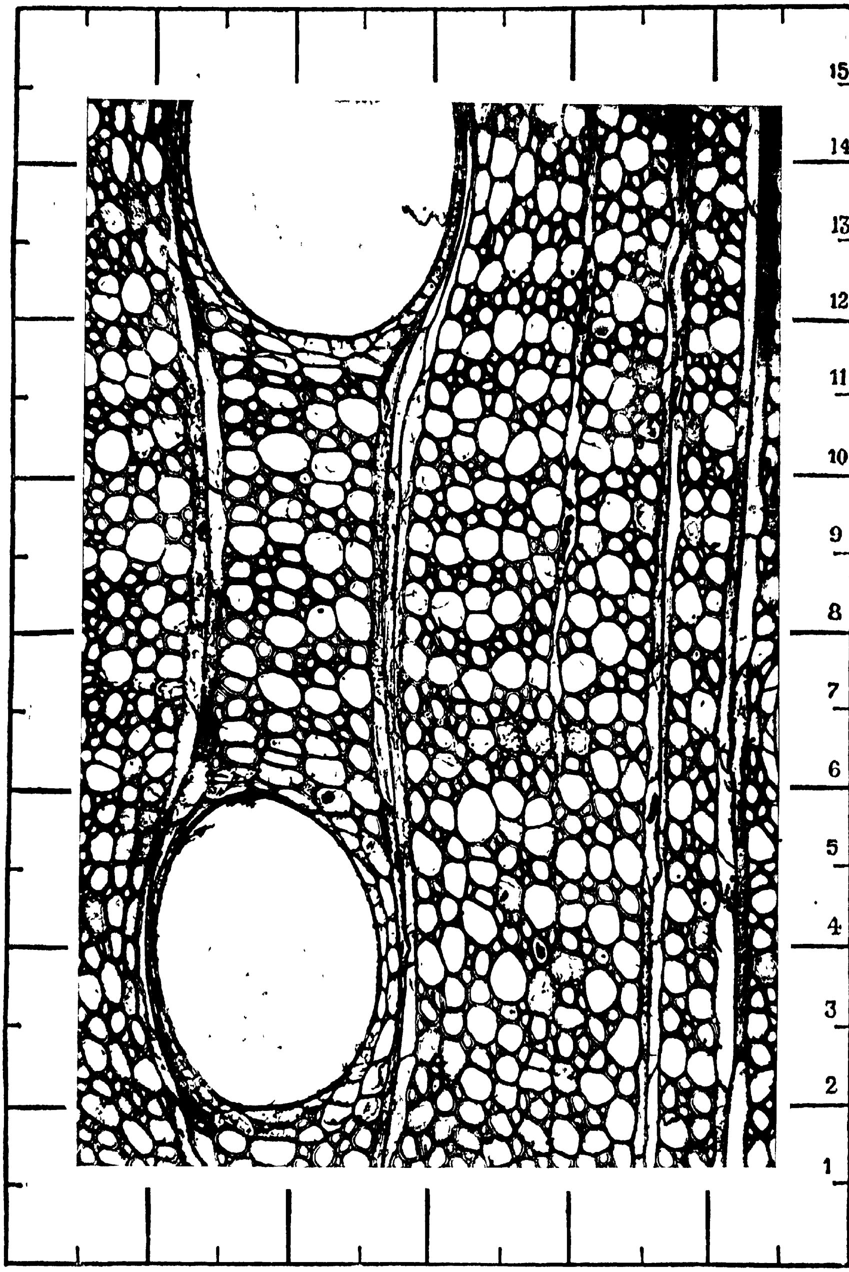


Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

ACACIA LEUCOPHLŒA, Willd.

Plate XVI.



Scale: one space = $\frac{1}{10}$ Millimeter = 100 Microns = $\frac{1}{250}$ inch.

Photomicrograph by H. P. Brown.

BOMBAX INSIGNE, WALL